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DEVELOPING A MODEL FOR ASSESSING THE EFFECT OF PHYSICAL INDOOR ENVIRONMENT QUALITY ON TEACHERS' PERFORMANCE IN SAUDI EDUCATIONAL BUILDINGS

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This thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy.

This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose (unless otherwise indicated). Save for any express acknowledgments, references and/or bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person.

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Date: 07/2018

Abstract

The nature and quality of the built learning environment affect occupants' comfort, wellbeing and performance. Within the broad range of studies of the physical indoor environment reported in the literature, there are several which have focused on the effects of these environmental conditions on the comfort and physical health of students and teachers, while the main consideration in others is the organizational health of the school. The parameters, which are measured often concern the state and condition of the physical environment. Categories of building features, which appear to influence comfort, health and wellbeing, include thermal sensation, acoustics, lighting, air quality, classroom equipment, learning resources and other aspects of the teachers' workspace. Those components of the physical of indoor environment, which are considered to most strongly affect occupants' comfort, wellbeing and performance, are subject to sets of standards.

The aim of this study is to elucidate the association between the indoor environmental quality (IEQ) of educational buildings and teachers' performance. Following a comprehensive review of the literature on the effects of IEQ on teachers' comfort, wellbeing and performance, a case study was conducted in which physical measurements were made of a range of indoor environmental variables in the classrooms of a technical college in Saudi Arabia, during lessons. At the same time, the teachers of those classes were asked to complete a questionnaire designed to investigate the quality of the indoor environment and explore teacher performance. An artificial neural network was then used to create an assessment model in order to test the hypothesis that the quality of the indoor physical environment in educational buildings is related to teacher performance and to predict future data.

This research makes both academic and practical contributions to the study of the relationship between IEQ and teachers' performance. The findings of this research will be used as a primary knowledge resource for future researches and to identify initial IEQ parameters and tools for further in-depth studies. In practical terms, it offers standards to help designers to consider the importance of IEQ and its impact on building users.

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List of Abbreviations

AHP	Analytical Hierarchy Process
ANN	Artificial Neuron Network
ANSI	American National Standards Institute
AQG	Air Quality Guideline
ASA	Acoustical Society of America
ASHREA	American Society of Heating, Refrigerating and Air Conditioning Engineers
b_j	Bias value
BB	Building Bulletin
BFG	Broyden–Fletcher–Goldfarb
BP	Back Propagation
BUS	Survey and the Building Use Studies
CBE	Center of the Built Environment
CEN	European Committee for Standardization
CFM	Cubic Foot per Minute
CGF	Conjugate Gradient backpropagation with Fletcher-Reeves updated
CGP	Conjugate Gradient backpropagation with Polak-Riebre updated
CO	Carbon Monoxide
C^o	Degrees Celsius(temperature measurement)
CO2	Carbon Dioxide
COPE	Cost-effective Open-Plan Environment
DASE	Design Appraisal Scale for Elementary school
dB	Decibels (sound pressure levels measurement)
EA	Evolutionary Algorithm
EN	European Standard
EPA	Environmental Protection Agency

GD	Gradient Descent backpropagation algorithm
GDM	Gradient Descent with Momentum
GSA	General Service Administration
HOPE	Health Optimization Protocol for Energy
HVAC	Heating Ventilation Air Condition
Hz	Hertz
IAQ	Indoor Air Quality
IEC	International Electro-technical Commission
IEQ	Indoor Environmental Quality
IES	Illuminating Engineers Society
IESNA	Illuminating Engineering Society of North America
ISO	International Organization for Standardization
JTC	Jeddah Technical College
L	Layers
L/s.	Litter per second
LM	Levenberg–Marquardt backpropagation
LMS	Least Mean Squared
Lux or lx	Luminous flux per unit area (illuminance measurement)
m/s	Meter per Second
MAE	Mean absolute error
min_ grad	Minimum performance gradient
MLP	Multilayer Learning Perceptron
MSE	Mean Squared Error
mu	Momentum values
mu_ dc	mu decrease factor
mu_ inc	mu increase factor
mu_ max	Maximum mu
N	Neurons
NAEYC	National Association for the Education of Young Children
NIOSH	National Institute for Occupational Safety and Health
nntool	Neural Network Toolbox
NRC	National Research Council Canada
OSHA	Occupational Safety and Health Administration
P	Momentum parameter

PM	Particulate Matter
PMV	Predict Mean Vote
POE	Post-Occupancy Evaluations
PPD	Predicted Percentage of Dissatisfied
PPM	Part Per Million (CO2 measuerment)
R	Regression of correlation coefficient
R^2	Coefficient of determination
RH	Relative Humidity (%)
RMSE	Root mean square error
RP	Resilence backpropagation
SBS	Sick Building Syndrome
SCG	Scaled Conjugate Gradient
SO_2	Sulphur dioxide
SPSS	Statistical Package for Social Science
SSE	Sum of Squared Error
$f(x)$	Mathematical function
TVOCs	Total Volatile Organic Compounds
USEPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
$w_{i,}$	Weights between input and hidden layers
$w_{i,j}$	Weights between hidden and output layers
WHO	World Health Organisation
$x_{\max}$	Maximum observed value
$x_{\min}$	Minimum observed value
$x_{\mathrm{o},i}$	Input observed value
$x_{\bar{o},i}$	Averaged observed values
$y_{t,d}$	Desirable output
$y_{t,p}$	Predicted output
a_k	Learning rate
$\Delta\ w_k$	Vector of weight changes
$\mu g/m^3$	Micrograms per Cubic Meter

Chapter 1

Introduction

The importance of physical indoor environmental quality (IEQ) in educational buildings should not be underestimated. It has become a significant public health issue. The effects of poor IEQ on the occupants of offices, commercial premises and educational buildings are reported to include health problems related to building condition (Kreiss, 1988; Mendell and Heath, 2005; Wargocki and Wyon, 2013) that effect occupant's performance. Inadequate consideration of physical indoor environmental parameters in the design of school buildings creates uncomfortable conditions for both staff and students, which can distract these occupants and impair their performance. These considerations have inspired worldwide research into the physical IEQ of educational buildings.

This chapter presents the background, aim, objectives and motivation of the present study and describes the problems associated with the research area.

1.1 Introduction

Within the built environment, the physical indoor environment and its occupants constitute a complex system, because most people spend a large proportion of their time inside buildings such as schools, offices and homes, engaging in dynamic behavioural interactions of various kinds. The environmental quality of these spaces has been found to affect human health, wellbeing and performance (Kuo and Don 2009; Di Giulio et al., 2010; Bluyssen, 2014). Students and teachers spend many hours in classrooms, where a good indoor environmental quality (IEQ) is shown to affect their teaching and learning performance positively (Fromme, et al., 2007). Furthermore, when a school environment is transformed to ensure healthy conditions, the outlooks of the teachers, students, parents and the wider community become more positive, resulting in improved teaching and learning outcomes (Berner, 1993).

The environment more generally interacts with people continuously and dynamically and has physiological and psychological impacts on them. It can consequently lead to effects in health and wellbeing, with strong economic implications for performance (Fisk, 2000; Heath and Mendell, 2002; Wargocki and Wyon 2013; Wargocki and Seppänen, 2006; Bakó-Biró et al 2008; Lan et al., 2014; Lieble et al., 2012).

IEQ can be defined as “the quality of a building’s environment in relation to the health and wellbeing of its occupants, and includes aspects of design, analysis, and operation that lead to energy efficient, healthy, and comfortable buildings” (NIOSH, 2013).

The concept of IEQ is comprehensive and depends on many indoor environmental variables, which can be grouped into four basic components that define the quality of the environment of spaces and its acceptability to users, namely thermal comfort, indoor air quality (IAQ), visual and acoustic comfort (Wong et al., 2008; Franchimon et al., 2009; Alfano et al., 2010; Frontczak and Wargocki, 2011). Several other studies (Kolleeny, 2003; Gou and Siu-Yu Lau 2013; Lai et al. 2009; Paul and Taylor, 2008; Vil et al. 2017; Kamaruzzaman et al., 2011) have documented various factors that affect occupants' performance and wellbeing, including contact to nature and daylight, air quality, odours, temperature, noise and ergonomics as well as opportunities for relaxation and social experiences. These variables influence staff morale and the behaviour of teachers; they thus affect the input and performance of teachers in educational buildings, with significant consequences for learning outcomes (Temple, 2007; Higgins et al., 2005; Sanoff, 1995). There is a body of research into the effects of IEQ factors on occupants' comfort and wellbeing. Several studies have quantified the relationship of comfort with thermal conditions (such as temperature and humidity), air quality, visual quality and acoustic quality, based on the adaptive comfort model, which proposes that comfort is a variable condition affected by psychological, behavioural and physiological practices (Humphreys and Humphreys 2016). Adaptive models run evidence that people adjust themselves and their immediate environment to increase comfort levels.

Determining which specific IEQ factors influence occupants' comfort and in what ways will provide designers with indicators to inform their decisions on future building projects. Consideration of occupants' perceptions of the effects of IEQ components on their comfort and performance can help designers to identify any problems and to find solutions that may improve comfort levels. Providing employees with a comfortable indoor environmental design may enhance their job satisfaction and performance, thus improving the organization's performance (Newsham et al. 2009; Vischer, 2007; Wyon, 2004). Studies have concluded that employees who are not comfortable with their jobs and workstation facilities have poorer performance and are more likely to intend to leave (Carlopio, 1996; De Dear, et al. 2015).

Kennedy et al (2006) claims that the quality of the physical environment in school buildings, where most teaching takes place, affects the ability of teachers to teach, their interest in teaching and their confidence, as well as their health and safety. When teachers suffer from poor classroom conditions, low salaries and a declining social environment, these factors may cause negative behaviour, reduce the quality of teaching and increase absences.

While there is plentiful IEQ literature evaluating office buildings, insufficient attention is paid to the condition of school buildings (Lee et al. 2012), despite the length of time that students and teachers spend there and the consequences that this has for the effect of indoor environmental conditions on their health and on school performance. There is strong community demand for better conditions in school buildings, to improve students' learning outcomes and the overall educational experience, hence the necessity for more research into the influence of IEQ on students' and teachers' performance (Catalina and Iordache, 2012). Indeed, the IEQ of classrooms is now great opportunity to the economy and future of any country, because it affects both the wellbeing and the performance of all users.

Humphreys (2005) notes that occupants' degree of comfort or discomfort with one or more IEQ factors does not necessarily reflect their overall environmental comfort. Thus, it is important to investigate the IEQ of classrooms in an inclusive way that includes all IEQ aspects, so that the contribution of each IEQ parameter can be determined and interactional effects can be understood. This research therefore explores the various IEQ factors that influence the performance of teachers and academic staff (teacher assistants) in educational buildings. It uses a theoretical framework to investigate the relationship of IEQ to performance and to understand the effects on teacher's comfort of range of IEQ factors, in order to determine how quality of classrooms influence teachers' performance level.

Some existing IEQ literature calls for improved evidence-based guidelines on building operation to enhance occupant performance and comfort. This study addresses the importance of measurable parameters in determining the effects of the physical environment on teacher comfort. Its findings include a review of the reliability and construct validity of the teachers' evaluation. Importantly, the study indicates which aspects of the indoor physical environment are the strongest indicators of teacher comfort and performance. The need for more studies on the effects of IEQ on occupants justifies the decision to investigate users' perceptions of IEQ. More specifically, while many researchers have focused on qualitatively assessing occupants' perceptions of IEQ and their comfort, the present study investigates quantitatively the associations of measured IEQ factors in classrooms with survey assessments of teacher comfort, wellbeing and performance.

1.2 Research Motivation

One-fifth of the world population spends the plenty of their time in schools and universities, which makes this study significant, because a comfortable body create a fresh brain to absorb knowledge and job efficiently (Lizzio, 2002).

Most previous IEQ studies have focused on the workstation, especially offices, and on residential buildings, rather than on schools or higher education institutions (Kielb et al., 2015). However, schools are particularly likely to have poor indoor environmental conditions because of shortages in the funding of school operations and other facilities (Schneider, 2002). Given that students and teachers spend almost as much time at school as at home, the school environment must have significant effects on both students' and teachers' health and performance (Mendell and Heath, 2005).

Hanushek and Rivkin (2009) suggest that "teachers might be willing to take lower salaries in exchange for better working conditions" and argue that salaries are not the only important consideration; teachers' preferences in terms of job and school environment can be just as significant.

The relatively small improvements in performance as a result of ensuring that employees are physically and psychologically comfortable can have potentially large economic benefits (Becker et al. 2007). Improving IEQ can save money. According to Fisk (2000) and Fisk et al. (2007), "the United States could save between $6 billion and $14 billion annually from reduced respiratory illnesses, $1 billion to $4 billion from reduced asthma, $10 billion to $30 billion from reduced Sick Building Syndrome (SBS) and $20 billion to $160 billion from worker performance gains. Controlling the thermal environment and lighting of the workplace can improve workers' performance with financial gains in the range of $12 billion to $125 billion annually. Annual productivity gains between $17 billion and $164 billion have been associated with improved air quality".

Kielb et al. (2015) examined the relationship in New York public schools between teachers' satisfaction and classroom features that related to inadequate of IAQ and building conditions associated with health symptoms. However, no study to date has investigated teacher health symptoms associated with the collection of comprehensive data on aspects of IAQ that relate to classroom characteristics. Several informative studies have either focused on one IAQ factor or have considered the whole indoor environment. The only studies practically focusing on teachers have explored health symptoms in buildings (Ebbehoj et al., 2005), poor IAQ and health symptoms (Schneider, 2003) and teachers' sick leave regularity related to student evaluations of school IAQ (Ervasti et al., 2012). Therefore, there is a significant opportunity to study this topic globally, specifically in the Middle East region with its hot, dry climate, in order to provide rich and valuable knowledge of the physical indoor environment, due to the lack of such studies.

1.3 Research Problem

Researchers such as (Lee et al. 2012) assert that insufficient emphasis has been placed on the importance of IEQ in school buildings. While some studies have been done in various parts of the world, a review of the literature (Chapter 2) reveals little empirical evidence of the effects of the total range of physical IEQ variables on occupants' comfort, health, wellbeing and performance in educational buildings.

Poor IEQ has been observed in educational buildings in countries including the United Kingdom, the United States, and Belgium. High levels of CO_2 have been measured and the concentrations of measured gaseous pollutants in schools were 50% beyond acceptable levels (Elena et al., 2011). Classroom temperatures were 3 to 6 °C above what teachers and students preferred. The main reason for high temperatures was considered to be that the ventilation rate in selected classrooms was inadequate to counteract the overheating caused by sunlight entering through the large glazed façade, which had been designed to offer as much natural lighting as possible. Windows also often remain closed to eliminate external noise and prevent draughts; however, high temperatures have been recorded in naturally ventilated schools as well as those with inadequate mechanical ventilation (Wargocki and Wyon, 2013).

Lan et al. (2011) state that appropriate ventilation systems not only deliver thermal comfort but also allocate adequate fresh air to teachers and students, eliminate pollutants and sustain IAQ and thermal comfort. However, 64% of classrooms not applicable to thermal comfort standard. Classroom ventilation in several schools is insufficient which considered the main source of health issues such as headache, respiratory allergy and fever. Approximately 50% of all health conditions are caused by respiratory problems because of poor air quality and levels of CO_2 in excess of 4000 ppm. This is also because ventilation level do not adequately meet the ASHREA standard for fresh air supply rates of 8 l/s per person and CO_2 levels of 1000 ppm (Lan et al. 2011). According to Hanushek (1999), in the United States and in European countries, the average class size was 23 students, corresponding to an occupancy amount ranging from 2 to 3.1 m^2 per person. However, Saudi schools generally conform to an archetypal design where classrooms are typically of rectangular form with an area of 58 m^2 occupied by an average of 30 students, giving an average capacity of 1.9 m^2 per person (MoE, 2018). The high occupant density of classrooms cause high temperatures, odour and various indoor pollutants.

Schneider (2003) and Buckley et al. (2004) surveyed teachers in Washington, DC, and Chicago and found that more than half reported a problem with air quality as the most frequently cited health complaint; one-third of the teachers suffered from health problems due to poor school environment. More than 21% of the Washington teachers stated that the lighting in their classrooms was inadequate. According to Samani (2012), many classrooms have high noise levels that interfere to conversation, making it difficult to follow lessons, with consequences for students' academic achievement and problems for teachers, who underperform due to inadequate acoustic environment. In some schools located in noisy areas, windows tend to be kept closed to reduce noise, which causes overheating in hot season and poor IAQ due to the absence of ventilation system (Montazami, 2012).

The present study explores the effects of indoor physical environmental variables on teachers' performance in Saudi educational buildings, because no previous study of Saudi classroom environments has examined the possible influence of different environmental factors on teachers' interactions and activities, nor has there been any evaluation of the comfort provided by the combination of IAQ and thermal, visual and acoustic conditions (Taleb and Sharples, 2011; Alyami et al., 2013). Only two studies (El-Sharkawy, 2014; Alsubaie, 2014) have objectively investigated the condition of Saudi school buildings in terms of their indoor physical environment. These were limited to the parameters of indoor air quality, since Saudi Arabia has no compulsory construction codes or regulations that incorporate the principles of sustainable building.

In Saudi schools, El-Sharkawy (2014) reports having found the highest levels of all pollutants inside classrooms that were located directly on streets with moderate traffic activity, rather than those with very low traffic flows. Mean levels of benzene, CO_2 and SO_2 were exceeded the air quality guideline values recommended by the World Health Organisation (WHO) in Europe. The WHO (2005) guidelines specify maximum noise levels of 35 dB in classrooms and 55 dB in outdoor playgrounds, but in schools in Jeddah, in western Saudi Arabia, the mean value was recorded to be much higher, at 60-89 dB, often due to the noise of classroom activities (Alsubaie, 2014). The present study of IEQ conditions in Saudi schools is significant in investigating the perceptions of indoor comfort of teachers and other academic staff in a hot climate.

1.4 Research Aim

“The presence of IEQ in buildings maximises the potential of the architectural form while optimising human comfort and wellbeing, as well as having an economic aspect” (Zunde and Bougdah, 2006).

The aim of this research is to develop a model for assessing the effect of physical indoor environment quality on teachers' performance in educational buildings in Saudi Arabia, in order to help to investigate the relationships of IEQ parameters with teachers' performance and to determine the relative importance for that performance of variables within the physical environment.

1.5 Research Questions

The research addresses the following questions:

Q1: What are the various factors related to the indoor physical environment that affect classroom conditions and comfort in Saudi schools?

Q2: How do physical environments in educational buildings affect teachers' comfort and influence performance in Saudi schools?

Q3: Which indoor physical environmental factors have the greatest effects on teacher performance in educational buildings in Saudi Arabia?

Q4: What methods can be used to explore teachers' comfort and performance as related to indoor environmental factors in Saudi schools?

1.6 Research Objectives

This study has four distinct but interrelated objectives:

- To identify by means of a literature review the variables of the indoor physical environment and to investigate the effects of its quality on teachers' performance in Saudi schools.
- To conduct a survey and case study to assess the quality of the indoor physical environment of Saudi Arabia educational buildings such as classrooms for primary data.
- To develop a model of indoor physical environmental factors that are identified by a review of the literature concerning Saudi schools.
- To classify (by means of weighting schemes) the indoor physical environmental factors that affect teachers' performance in Saudi educational buildings.

1.7 Research Scope and Limitations

This research focuses on identifying the relationships between indoor physical environmental variables and teacher performance in educational buildings in Saudi Arabia by building an assessment model to investigate the interactions among these independent and dependent factors. Eight physical indoor environmental factors were selected for investigation through objective measurements using recommended instruments and sensors, while a subjective approach was taken to evaluate teachers' perceptions of various indoor environmental parameters. This study has a limited focus on those aspects of physical comfort that are directly related to the physical features of the indoor environment of classrooms, while accepting that other dimensions should be considered in some cases. Teachers' comfort in response to elements of IEQ is highly subjective and depends on various independent variable such as behaviour, attitude and mood. The study therefore recognizes the complexity of understanding and measuring the relationship between IEQ and teacher performance.

1.8 Overview of Research Design and Methodology

A research design is a procedure to describe how a particular researcher interprets the task of conducting research. A guiding principle for establishing any research design is that the chosen design must allow the researcher to answer the research questions comprehensively (Creswell, 2003). Therefore, it is worth presenting an overview of the methodological approach taken in this study. The research approach provides an outline of data collection techniques and a discussion of the initial research questions based on the data, as well as measures of indoor physical environmental variables.

Smith et al. (2012) state that the research approach includes defining the type of evidence adduced, as well as the process of interpretation used to obtain reasonable responses to the research questions and objectives. This research proposes a comprehensive methodology to evaluate physical IEQ and teachers' comfort, wellbeing and performance in school buildings based on adaptations of existing workplace post-occupancy evaluation methods. A significant aspect of this research design is that it comprises a specific case study and adopts two strategies (the experimental measurement of IEQ parameters, and an assessment survey) as well as the method of developing an assessment model.

1.9 Thesis Outline

This thesis consists of seven chapters. The first has introduced the study, providing an overview of research into the physical indoor environment, its quality and its effects on comfort and performance. It has also outlined the importance of studying the concept of the indoor physical environment as a considerable component of users' comfort and identified the motivation for this research. It has stated the aim and objectives of the research and delineated the methodology to be used.

The second chapter is a literature review, providing more detail of the concept of IEQ and its impact on the occupants of buildings, focusing on the definition of IEQ and the extent of its effects on comfort, wellbeing and performance in educational buildings. There is a comprehensive review of studies of indoor physical environmental factors (thermal conditions, air, light, acoustics, layout, look and feel, view, amenities and location) which have explored the conditions that influence teachers' performance, with the aim of determining the indoor environmental variables that have the strongest physical effects on comfort, wellbeing and performance.

Chapter 3 is concerned with the methodology that was used to test the research hypotheses and to achieve the aim of the study. It covers research philosophy, approach and design, as well as methods of data collection and analysis. It justifies the choice of research strategies, namely case study, questionnaire survey and objective measurements of IEQ parameters. The data collected by these means are analysed and interpreted in Chapter 4. The process of analysis consists of exploring, presenting and describing the collected data.

Chapter 5 describes the development of a statistical model to evaluate IEQ and performance, using the artificial neural network technique and the training algorithm method. The model, designed to correlate the relationship between IEQ and teacher comfort, wellbeing and performance, was developed through many stages to optimise its efficiency. The parameters of the indoor physical environment are classified using various indices to determine the strength of the effect of each on teacher performance. This is followed in Chapter 6 by a comprehensive discussion of the research findings and a comparison with findings reported in the literature.

Chapter 7 concludes the thesis by summarising the findings of the study. The research objectives as initially formulated are revised, providing answers and determining whether the results meet those objectives. The chapter draws the main conclusions of the study, sets out its contribution to IEQ knowledge and makes general recommendations. It ends by making suggestions for future research.

1.10 Conclusion

This chapter has established the need to explore the parameters of the indoor physical environment of educational buildings and their effects on teacher performance, which requires a theoretical framework within which to determine the association between IEQ parameters and performance, so that the quality of classrooms can be improved by ensuring that these parameters correspond to the occupants' comfort and wellbeing. This research therefore aims to develop a model for assessing the effects of the indoor physical environment on teacher performance. Several studies of the relationship between indoor environmental quality and performance have found strong support in various conditions and contexts, especially in developed countries, but importantly, such studies have been scarce in developing countries, as is clear from the literature review which follows.

Chapter 2

Literature Review

This chapter presents a review of the literature dealing with the most important aspects of the physical indoor environment. It begins by considering the physical IEQ factors that affect occupants' comfort, wellbeing and performance, then reviews the most widely cited models of thermal comfort and recommended IEQ standards. Overview of educational building in Saudi Arabia was conducted to understand the context of this study. Thus, the chapter helps to answer questions regarding what the relevant IEQ factors are and how they affect a building's occupants. Most importantly, it addresses the significant effects of these variables on performance.

2.1 Introduction

An appropriate building design will enhance the environmental quality inside its architectural spaces to ensure the comfort and health of the occupants. In the context of this study, the value of providing good environmental conditions in classrooms lies primarily in their benefit for the teachers and students, with the consequent improvement in their performance of their teaching and learning tasks and thus the improved performance of the school itself.

The literature offers a number of broad theoretical frameworks for defining and categorizing the indoor environment variables that influence quality. The central concept addressed in this study is teachers' comfort in general. Vischer (2005) and Feige et al. (2013) identify environmental variables in several distinct categories, including physical ones (thermal comfort, air quality and light), functional comfort (tasks and activities) and psychological comfort (privacy and safety). This literature review focuses on those physical conditions that affect the quality of the indoor environment and consequently influence teachers' comfort, wellbeing and performance.

In order to provide a comprehensive account of the relevant concepts and relationships, the present study focuses on a selection of eight physical factors based on the findings of the studies reviewed. These variables are thermal comfort, indoor air condition, light/visual quality, acoustic quality, layout and arrangement, look and feel (colour and texture), view and biophilia, and location and amenities. It was essential to identify these factors before deciding on the best procedures for collecting the research data (set out in Chapter 3). It must be noted that some of the literature reviewed here concerns the effects of IEQ on the comfort of occupants of office and residential buildings, because of a paucity of research specifically addressing the school building environment and its effects on teachers' comfort and performance.

The framework of this study has guided the orientation of this literature review towards an examination of the relationship of IEQ to teachers' comfort, wellbeing and performance. It seeks to offer a comprehensive account of studies conducted to identify the most important of these factors, their contribution to the indoor environmental quality of the workplace, their effects on occupants' comfort and performance and the consequences for the occupants' performance. The chapter closes with a summary of various effect of IEQ on wellbeing and performance.

2.2 Literature Review Method

In order to ensure comprehensive coverage of the research topic, the sources of the literature reviewed here include journal articles, conference papers and books. The review was conducted in four phases, illustrated in Figure 2.1, to identify, collect and classify materials appropriate to this study.

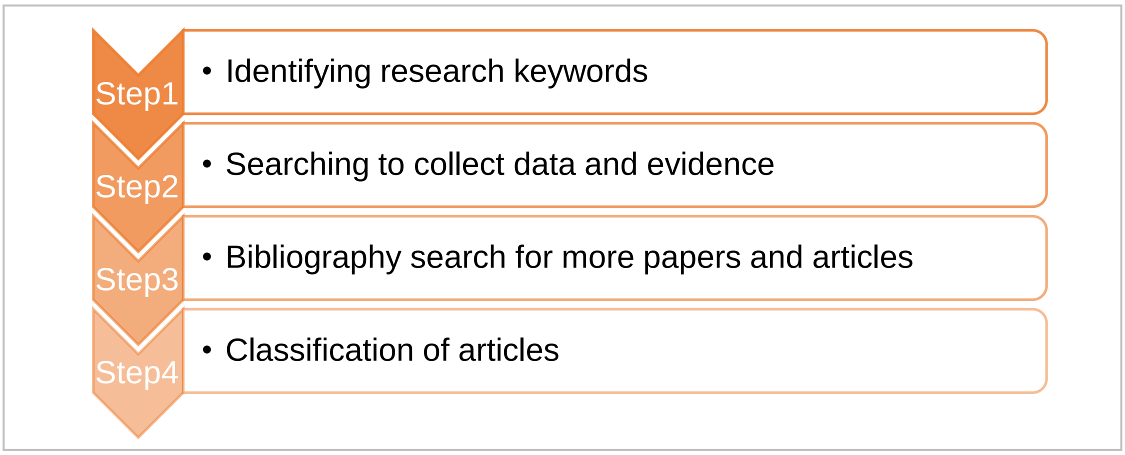


Figure 2.1: Literature review method

The first step was to specify keywords that would simplify the search and focus it on materials exploring the effects of IEQ on teacher performance and productivity in schools and educational buildings. The keywords chosen were *teacher performance*, *teacher productivity*, *occupant productivity*, *IEQ in school* and *teacher comfort*. The second step was to collect data and evidence about the different IEQ factors that influence teacher performance and the degree of impact on overall performance. The online research engine of the University of Salford library (SOLAR), University of Wolverhampton library and Google Scholar were used to search for materials. The third step was to search bibliographies to identify other sources of material that were relevant to the research topic and the final step was to classify the journal articles according to three criteria: name of journal, year of publication and orientation.

2.2.1 Journal classification

The papers identified for review by the online research tools were taken from 32 journals, listed alphabetically by title in Table 2.1.

Table 2.1: *Titles and publishers of journals consulted*

Journal title	Publisher
Advances in Building Energy	Taylor and Francis
American Educational Research Association	Sage
American Journal of Public Health	Science & Educational
Annual Review of Energy and Environment	UC Berkeley
Applied Energy	Elsevier
Applied Ergonomics	Elsevier
Applied Thermal Engineering	Elsevier
Building and Environment	Elsevier
Building Research and Information	Taylor and Francis
Center for the Built Environment	UC Berkeley
Construction Management and Economics	Taylor and Francis
Energy and Building	Elsevier
Environment and Behaviour	Sage
HVAC & Research	Taylor and Francis
Indoor and Built Environment	Sage
Intelligent Buildings International	Taylor and Francis
International Journal of Environment	Elsevier
International Journal of Scientific & Research Publications	Elsevier
Journal of Architectural Engineering	Elsevier
Journal of Corporate Real Estate	ASCE
Journal of Education Psychology	Emerald
Journal of Environment Science and Engineering	Sage
Journal of Environmental Psychology	Elsevier
Journal of Facilities and Management	Elsevier
Journal of Occupational Health Psychology	Emerald
Journal of Stress and Health	APA
Journal of the Acoustical Society of America	ASA
Lighting Research and Technology	SAGE
Renewable and Sustainable Energy Reviews	Elsevier
Science and Technology for the Built Environment	Taylor and Francis
Science of Total Energy	Elsevier
Social Science Research	Research Gate

2.2.2 Year of publication

The articles reviewed were classified by year of publication, focusing on recent developments and contributions to the field. Over 350 articles were reviewed, published from the 1970s to 2017. Figure 2.2 charts their distribution by decade, showing that a large majority were published in the 21st century, the decade most strongly represented being the years 2000 to 2009.

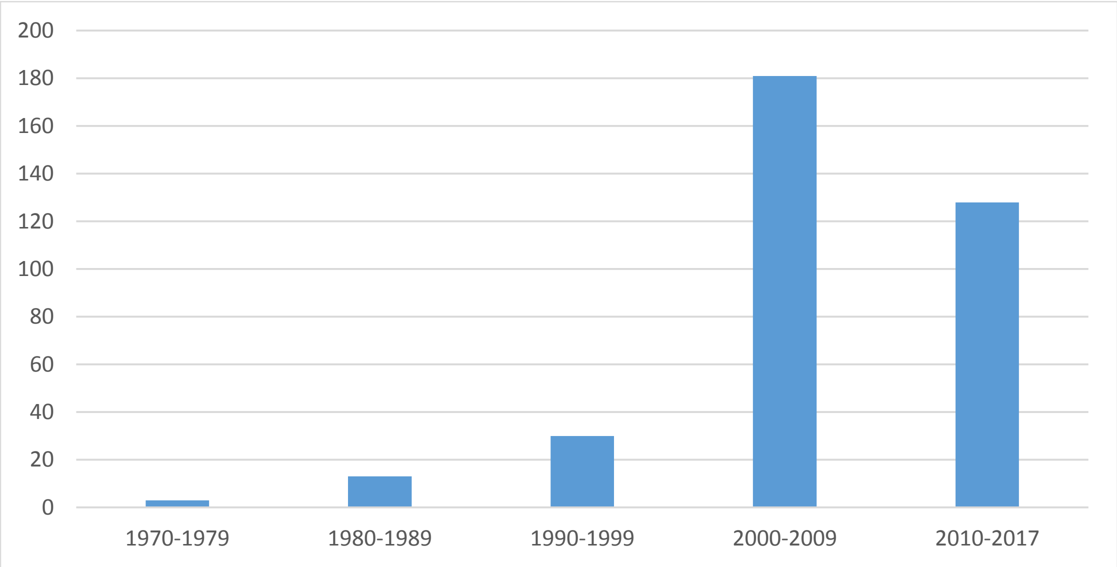


Figure 2.2: Number of articles reviewed by decade of publication

2.2.3 Orientation of articles

The articles were finally classified by orientation into the following categories: literature review/conceptual, focusing on earlier contributions and on theoretical models; case studies, whether of a few groups or of an organization; empirical studies whose data were collected by means of calibrated scientific instruments within large organizations; calculation/simulation, comprising articles based on simulation experiments; and others. Figure 2.3 charts the numbers of articles in each of these broad categories, showing that case studies were the most used, together with empirical studies, these constituted more than half of the review corpus.

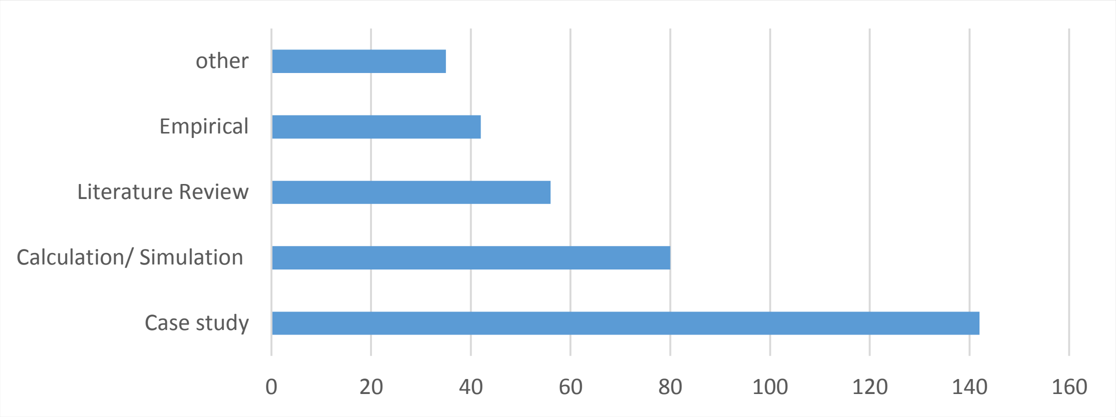


Figure 2.3: Orientation of articles reviewed

2.3 Physical Environmental Factors Affecting IEQ

The physical environmental variables that affect IEQ include many parameters that may have an effect on occupants, such as thermal comfort, indoor air quality (IAQ), ventilation flow rate, background noise, ergonomics and lighting quality (Lee et al., 2012). Among these, the majority of studies focus on thermal comfort, IAQ and ventilation, which constitute the prevailing concerns for comfort and performance (Choi et al., 2013).

Heinzerling et al. (2013) advise that “a review of every aspect separately and in relation one to another is crucial to understanding the intricate relationships between them”. Thus, a combination of these factors underlies the complex relationships involving IEQ. There appear to have been more studies of thermal comfort than of any other IEQ elements in the literature, mostly due to the close relationship between the antecedents of thermal comfort (heating, ventilation and air-conditioning) and energy consumption.

The following subsections review in turn the physical environmental factors most widely considered to affect teacher comfort, wellbeing and performance, emphasizing the relationships of school IEQ with teacher behaviour and the extent of these effects.

2.3.1 Thermal comfort

Thermal comfort is defined as ‘‘that condition of mind which expresses satisfaction with the thermal environment” (ASHRAE Standard 55-2004). The human response to comfort can be conceived in terms of three conditions: thermal sensation, thermal acceptability and thermal preference. *Thermal sensation* can be defined as the perception of the thermal environment, *thermal acceptability* as the degree to which occupants accept the thermal environment and *thermal preference* as the ideal thermal environment (Langevin et al., 2013). The major factors that affect thermal comfort include “relative humidity, heat, dry bulb temperature, radiant temperature, air velocity, the human metabolic rate and the insulation rating of clothing” (Li lan et al., 2014). Thermal comfort is considered the most important parameter in IEQ evaluation, as measured by the number of complaints. Natural ventilation, i.e. opening windows and doors, can play a major role in thermal comfort and opening classroom windows has the potential both to reduce CO_2 concentration and to save energy. However, teachers often avoid windows from being opened (Pinto et al., 2014); in the present research, it was observed that windows were kept closed to reduce the heat gain from outside in the hot climate.

The importance of thermal comfort in the indoor environment should not be underestimated, especially in educational buildings, where it affects the wellbeing and performance of both students and teachers. Thermal discomfort is an unsatisfactory condition for them, liable to distract them from teaching and learning well. This is why thermal comfort in buildings has been studied in many countries over the world (Wargocki and Wyon, 2006).

The comfort of occupants is affected by behavioural, physiological and psychological factors. Humphreys and Nicol (2007) suggest that the physiological process of thermal regulation between the metabolic system and the immediate environment may be the most essential dimension of quality in term of physical environment. Temperature is considered the best indicator of thermal comfort, which has a significant psychological dimension, interacting continuously with it to affect the perceptions. The conditions of temperature and relative humidity should also be maintained at appropriate levels to minimize any allergies and sensitivities among users, such as asthma, headache and eye strain. Bargh and Shalev (2012) showed that experiences of “physical warmth” elevated feelings of social behaviour among students and staff, thus potentially boosting the positive perception of the environment and enhancing performance.

There is a wide range of factors that directly and indirectly influence thermal comfort, comprising environmental variables such as air temperature, relative humidity and air velocity, as well as personal characteristics including gender, age, activity level, clothing and individual differences. Consequently, predicting the range of temperatures that will provide a comfortable environment is complicated, depending not only on cultural influences, but also on climatic, environmental, geographical and individual factors, in addition to the types of task involved (Heath and Mendell, 2002; Wargocki, and Wyon, 2013). However, Sadat et al., (2016) state that little research has been done to quantify the extent to which these variables and the associated perceptions of comfort affect academic performance.

Designers and researchers use models of comfort to predict occupants’ comfort. Fanger (1970) developed a model for predicting thermal comfort that consists of four physical factors “(air temperature, mean radiant temperature, air velocity and relative humidity) and the human variables of clothing insulation and activity level, which together determine the Predicted Mean Vote (PMV) index”. This in turn is used to calculate the Predicted Percentage Dissatisfied (PPD) among the occupants. The model thus forecasts the percentage of building users who will be dissatisfied within a given set of thermal conditions. It predicts whether a large group of individuals are likely to feel too cold or too warm, recognized by voting -3, -2, +3 or +2 on the scale. Indeed, many studies have used Fanger’s PMV-PPD prediction model to estimate the actual thermal sensation of a building’s users (De Dear et al., 2015).

The two approaches most commonly used in predicting occupant comfort are the heat balance and adaptive comfort models. Heat balance models are based on the statement that occupants are generally comfortable under specific combinations of parameters. The design process involves weighting the environmental and personal variables to predict the percentage of occupants who will be uncomfortable (Frontczak and Wargocki, 2011). Adaptive comfort models, which have been developed in the last 20 years, predict occupant comfort based on the climatic conditions outside buildings. These models typically have a higher neutral temperature, assuming that the human body adapts to seasonal variation. Furthermore, occupants are more comfortable with a given temperature when they are able to control the ventilation rate and air velocity (Kim et al., 2013). These models are used in different environment conditions: heat balance models are applied to buildings with HVAC systems that centralize the heating, cooling and ventilation, whereas adaptive models are generally used in unconditioned spaces. Adaptive models estimate comfort more accurately than heat balance models, especially when thermal conditions are poor and in naturally ventilated places (Schellen et al., 2013). The evaluation of comfort in these models is based on experimental findings from surveys using a Likert differential scale from hot to cold (ASHRAE, 2013). The heat balance model was used in this research via a survey to evaluate participants' feelings about their thermal sensations.

Determining optimal conditions for thermal comfort is complicated by the multiplicity of recommended standards. In the United States, the leading model is a heat-balance one defined by ASHRAE Standard 55-2004: *Thermal Comfort Conditions for Human Occupancy*. This uses activity level, clothing insulation and relative humidity to identify an acceptable effective temperature range. The temperature can be adjusted to take account of air velocity, and limits are given for the healthy asymmetry of surrounding environment. ASHRAE standard 55-2004 has a section for the application of adaptive comfort models to mechanical cooling systems, whereby the recommended temperature lies between 20 and 24.5 °C.

The *Performance Criteria of Buildings for Health and Comfort* (Bronsema, 2004) adopts a similar methodology to ASHRAE standard 55 but makes separate recommendations for summer and winter values. For school buildings, this guide recommends 24.5 °C in summer and 22.1 °C in winter. The standard also offers recommendations for designing the relationship and interaction between thermal comfort and perceived air quality. In the CEN/TC 156 technical report CR 1752 (1998), the suggested temperature for schools in Europe is 23.5 °C in summer and 20 °C in winter.

Humidity is another important indoor environmental parameter. Schneider (2002) found an association between relative humidity in school buildings and student absenteeism, indicating that more students feel ill when humidity levels are higher in classrooms, because fungal growth increases under these conditions. In a meta-analysis of studies, Seppänen and Fisk (2006) report that SBS symptoms increased by 12% for every 1 °C above 28 °C. They also found that the performance of occupants was optimal at 21.5 °C. Temperatures outside the range of 20-23 °C corresponded to a reduction in occupant performance of about 10%. In another study, Nakano et al. (2002) discovered that higher temperatures caused problems in mathematics classes: teacher performance declined as a result of increasing mental load, as measured by brain blood flow.

Nasrollahi et al. (2008) conducted a study to determine how thermal comfort influenced occupants' comfort and performance. They investigated occupants' perceptions of comfort and compared the thermal conditions of six office buildings with recommended standards set by the ASHRAE. Half of the participants were comfortable with the temperature even when objective measurement showed it to be below the recommended ASHRAE standard, whereas when the temperature exceeded the ASHRAE acceptable standard, 80% of occupants were comfortable with it and only 20% reported discomfort. Generally, 23% of occupants were thermally uncomfortable and approximately 80% stated that thermal comfort could improve their performance.

Thermal comfort has a significant impact on morale and influences the performance and wellbeing of occupants. In contrast, thermal discomfort in buildings create unhealthy conditions for both teachers and students and can increase complaints (Wargocki and Wyon, 2007; Barbhuiya, 2013).

Thermal control is essential to the productivity of students and teachers' performance in classrooms, while a lack of control contribute to more absenteeism and lower achievement. Enabling people to control the indoor environmental conditions increases comfort level with the thermal, acoustic and visual environment, as well as with air quality; however, two studies have found that access to such control did not affect thermal comfort (Melikov et al., 2005) and visual comfort (Newsham et al., 2009).

Andersen et al. (2009) evaluated the effect on comfort of occupants' perceived personal control over thermal conditions (via ventilation) through an online survey. The results show that the occupants of naturally ventilated offices were more comfortable than people in mechanically ventilated buildings, because they were able to control their environment through their access to thermostats and to the natural ventilation provided by windows, whereas the thermal environment of mechanically ventilated buildings is controlled by technology sensors and the windows are inoperable. The study also found that occupants were more comfortable with their ability to control the environment and reported fewer perceived undesirable temperature and drafts.

2.3.2 Air quality

The cleanliness and gaseous composition of the air together make an essential contribution to human health and comfort. Indoor air quality is characterized by physical and chemical components, such as temperature, relative humidity and contaminants, which are affected in turn by factors such as climate, building conditions (age, materials and construction), the heating, ventilation and air conditioning (HVAC) system, indoor layout design (furniture and equipment), air pollution sources and occupants' activity and behaviour. These parameters are all involved in differing dynamic interactions (Szczurek et al., 2015), making it difficult to identify direct causes of discomfort and health symptoms in the presence of both indoor pollutants and other indoor environmental factors. Kamaruzzaman et al. (2011) reviewed studies of workplace conditions and report that much attention was addressed to reactive measures regarding IAQ, while few studies are available to guide the construction of buildings to enhance IAQ and to minimize contamination levels and future hazards.

A survey by the Washington State Department of Health found that 25% of schools had IAQ problems and that identifying such problems cost an estimated average of $135,000, because construction and building systems factors are closely interrelated, making it difficult to address specific causes of IAQ problems. Classroom design must enhance IAQ by minimizing sources of contamination and maximizing ventilation flow rates by both natural and mechanical means. The level of indoor air quality will affect the performance of school building users; in particular, poor IAQ may cause disease and sickness requiring absence from school, while severe health conditions will reduce performance levels (EPA, 2010).

Various studies of the effects of IAQ have measured carbon dioxide (CO_2) level and used this to estimate the rate at which fresh air is delivered to occupants. The physical environment affects teachers' wellbeing, both physical and mental. The level of indoor air pollutants, including high CO_2 concentration caused by poor ventilation in classrooms, can affect teaching, because CO_2 is observed as a major of air pollution that contributes directly to augmented fatigue and loss of attention (Kajtar et al., 2006). Haverinen-Shaughnessy et al. (2011) measured CO_2 levels in one classroom in each of 87 schools to determine whether test scores improved with higher ventilation rates and found that there was some improvement.

The freshness of air is also commonly evaluated by measuring the concentration of volatile organic compounds and suspended particulate matter, whereas bioaerosols such as fungi and bacteria are evaluated generally by microscope or artificial growth tools (Stetzenbach et al., 2004). However, determining the specific composition of particulate matter and volatile organic compounds is costly in time and money, which may elucidate why these approaches are usually reserved for studies and sensitive occupancies.

Ensuring good air quality inside architectural spaces is not as easy as providing access to outdoor air, ever since in some cases, environmental contaminants are present outside. The challenging part of air quality is the difficulty to perceived (Clements-Croome et al., 2008). Building users may complain about CO_2 concentration and odours, which appear to provide good warning of air quality problems, but they are less likely to complain about either low ventilation flow rates or high organic pollutants. This means that occupants may present behavioural changes, discomfort, or health symptoms without relating these subjects to air quality (Heinsohn and Cimbala, 2003).

Previous studies have indicated that the concentration of CO_2 in buildings is a proper indicator of indoor air quality (Seppänen et, al. 1999). Research by Shendell et al. (2004) supports the use of CO_2 concentration as an indicator of pollutant concentration, showing that values above 1000 parts per million (ppm) in schools were associated with a 10-20% increase in absenteeism. It is argued that absence from school reflects poor IAQ amongst other variables and those respiratory illnesses tend to be more common in schools with insufficient ventilation. Schneider (2002) reviewed several studies indicating that higher ventilation rates improve learning and performance, because poor air quality adversely affects teachers' comfort and health, thus increasing absenteeism, reducing motivation to teach and ultimately impairing student outcomes. Mendell and Heath (2005) analysed air quality and thermal studies that illustrated the importance of these parameters for student performance. Moreover, higher levels of indoor humidity and organic (bacterial and fungal) pollutants are associated with increased asthma and respiratory illness, leading to reduced performance and attendance. The authors suggest that robust studies are needed to establish the nature and strength of the association between air quality and performance. Wargocki and Wyon (2007) found that higher air flow rates accounted for variance in the performance of some tasks by students and teachers. Interestingly, they report that when provided with more fresh air, students felt less hungry. The proposed mechanism for this association is that fresh air reduces stress, of which hunger is considered a proxy.

A recent study has revealed that CO_2 concentration is a reliable proxy for bio-effluents from occupants. It is consequently a good indicator of the occupants' numbers in a space and can be used to predict occupants' complaints about odour. However, CO_2 concentration does not give an accurate measure of the quantity of outdoor air supplied to a space (Li Lan et al., 2014).

The variety of air distribution techniques and ventilation controls displays the complexity of the IAQ literature. Haghighat and Donnini (1999) reported that a higher perceived air change rate was correlated to greater comfort with IAQ in office buildings. Air distribution techniques influence the stratification of pollutants and transmission of infections. Indoor air pollution could be minimized by the adoption of newer design solutions, such as displacement ventilation with underfloor air diffusers; however, Heinsohn and Cimbala (2003) state that these have not been adopted in most schools.

A major concern of IAQ studies is to identify the sources of contaminants. The type of flooring material, for example, may affect IAQ and thus the asthma risk in schools. Tortolero et al. (2002) measured the surface loadings of organic pollutants on carpets in 80 classrooms, finding that 30% of them contained unacceptable levels of fungal and insect allergens. Foarde and Berry (2004) compared classrooms with mostly tiled floors to one that was mostly carpeted, finding that the carpeting represented as a contaminant sink, giving higher surface loadings, although the hard flooring was associated with higher aerosol particulate concentrations. The acoustic and psychological variances between hard flooring and carpeting complicates the relationship of student and teacher performance with IAQ.

Bullock (2007) reports that students whose classrooms had hard tiled floors recorded higher test scores in mathematics than those with carpeted floors. However, the validity of the study was limited by the fact that only 5% of the 111 schools surveyed had carpeted classrooms.

The most significant flooring-related finding of a study by Fisk (2000) was that the removal of carpeting from buildings was associated with improved performance and outcomes such as reduced levels of physical contaminants, better air quality and less intense symptoms of sick building syndrome (SBS) such as headache and dizziness. The absence of carpets also affected performance, which improved by 6.5% in amount of text typed, by 2.5% and 3.8% in scores on a logical reasoning test and by 3.1% on a timed test. Self-assessments of performance indicate that improved performance may have been a consequence of the reduced incidence of headache.

Whatever its cause, poor IAQ may lead to building-related illness and to SBS, a condition in certain buildings in which people feel uncomfortable and suffer headaches, sleepiness, or the inability to concentrate (Heinsohn and Cimbala, 2003; Bronsema et al., 2004). A study by Takigawa et al. (2009) concludes that SBS is affected by the presence of high concentrations of indoor air pollutants, especially biological components, such as formaldehyde and volatile organic compounds.

Among other researchers who have found air quality to influence occupants' comfort and performance, Wyon (2004) estimates that poor air quality in office buildings may make employees very uncomfortable and their performance reduced by 6%. Schneider (2003) surveyed teachers in Washington, DC and Chicago to explore school conditions, finding that air quality was the highest health complaint referring to school facilities, that over half of respondents reported some problems and that a third of the sample reported suffering from health issues due to poor school conditions.

Kielb et al. (2015) conducted a study of 501 teachers in primary and secondary schools in New York State, most of whom reported classroom conditions potentially related to poor IAQ. Over 40% reported at least one health symptom such as headache, allergies and throat irritation connected with conditions within buildings. Most of the poor classroom conditions identified were correlated with one or more symptoms, the strongest correlations being with the presence of dust, paint odours and mould.

When poor IEQ causes employees to feel discomfort, their concentration to their work may also decrease. Conversely, employees focus well when air conditioning is run to reduce high temperatures and provide fresh air. Lorsch and Abdou (1994) showed that when the air-conditioning system was operated, employees felt more comfortable and were able to concentrate better, thereby improving their performance by between 5% and 15%. They also found that comfort levels in teaching spaces without humidity control could become unacceptable during the summer months. Controlling indoor humidity is considered a major factor of good IAQ and the provision of an ideal learning environment, because high humidity levels are associated with discomfort and the growth of microbiological agents.

Standard 62.1-2013: *Ventilation for Acceptable Indoor Air Quality*, published by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) specifies minimum rates of the supply of outdoor air to buildings based on a reduction approach to controlling pollutants. For a typical classroom, the minimum ventilation requirement is approximately 3 litres of outdoor air per second per person, equivalent to 0.47 cubic feet per minute (cfm), whereas a ventilation flow rate of less than 0.152 m^3/s is classified as ‘still air’. Such stagnation is unfavourable to IAQ, because particles of contaminants are static in the air that occupants breathe, which can affect their comfort and health.

The international standard was developed by the European Committee for Standardization Technical Committee on Ventilation in Buildings (CEN/TC 156) and outlined in the technical report CR 1752 *Ventilation for Buildings: Design Criteria for the Indoor Environment* (CEN, 1998). In contrast to ASHRAE standards, CR 1752 classifies three categories of achievement based on the estimated percentage of occupants who report discomfort with IAQ. The thresholds of 15%, 20% and 30% discomfort are connected with a ventilation rate ranging from 0.47 to 1.18 cfm/ft^2 for classrooms (Olesen, 2004). These three thresholds are associated respectively with CO_2 levels of 460 ppm, 660 ppm and 1190 ppm above the levels measured outdoors.

Bronsema et al. (2004) developed another design guide, *Performance Criteria of Buildings for Health and Comfort*, based on the standards of the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO) to specify upper limits of air contaminants. For example, the average concentration of inhalable particulate matter (PM10) should be no more than 150 micrograms per cubic metre ($\mu g/m^3$) in 24 hours, while respirable particulate matter (PM2.5) should be limited to 35 $\mu g/m^3$ (USEPA, 2015). However, the WHO has warned that levels of PM10 as low as 10-20 $\mu g/m^3$ are associated with increased health risk (Bronsema et al., 2004).

The Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) have determined limits for safe exposure to contaminants. NIOSH uses a ten-hour exposure period for establishing concentration limits, while OSHA uses eight hours (Heinsohn and Cimbala, 2003). The OSHA 8-hour maximum average for “particulates not otherwise designated” is 10,000 µg/m^3 of PM10 and 5000 µg/m^3 for PM2.5, although these are higher than the IAQ suggestions above.

The guidelines in the *IAQ Tools for Schools* action kit (USEPA, 2012) are addressed to school administrators and teachers. This resource includes simple yes/no checklists to identify sources of air quality problems and makes suggestions for addressing items of concern.

A review by Daisey et al. (2003) of a number of studies concludes that increasing the natural air ventilation rate would improve the performance and speed of schoolwork by about 14%. The interventions reviewed showed that performance on classroom tasks was significantly affected. The results demonstrate clearly that classroom air quality is a very important variable in the learning process and should be considered a serious educational priority, together with teaching resources and methods. Furthermore, air quality was found to be much worse in classrooms than in offices because this context had been neglected (Daisey et al., 2003).

In common with other workers, teachers should be able to exercise some control over temperature and ventilation conditions in the workplace (i.e. the classroom) because this would lead to improved performance, fewer symptoms of illness and less absenteeism. Such is the effect of air quality on performance that when temperature and ventilation were controlled, employees’ performance improved by 6.5% in suitable conditions. However, while providing adequate ventilation and removing sources of pollutants are correlated with improved health and performance, they often increase energy consumption (Haghighat and Donnini, 1999).

Teachers prefer to be able to open classroom windows. In a study comparing schools, Heschong et al. (2002) found that operable windows in classrooms enhance students to achieve 7% better results in reading and maths than those in classrooms with fixed windows. Schweiker et al. (2013) found that topics in a controlled study in a test chamber had higher skin temperature and drank more water when windows were not allowed to open, possibly due to worse air pollution. Barrett et al. (2015) recommend that orientation, shading devices and the size and position of windows be considered at the design stage to avoid glare, overheating and poor air quality.

2.3.3 Lighting quality

The main function of daylight in buildings is to provide an attractive and pleasing atmosphere and visual comfort. Visual comfort is defined as “a subjective condition of visual well-being induced by the visual environment” (EN 12665, 2002). There are two daylighting systems: side lighting, which involves a commonly used window opening, and top lighting, which involves an opening in the roof of the building, such as a skylight (Alrubaih et al., 2013).

The purpose of lighting design is to enhance illuminance, colour and lighting to achieve a quality of vision physically and psychologically acceptable to the users. Views diverge on the effect of lighting on performance: some researchers claim that there is no such effect, whereas others assert that lighting has a direct impact on mood and thus an indirect influence on performance (Rice, 2003). Most people spend a considerable proportion of their time in buildings, where uncomfortable environmental conditions, caused for example by poor building design or inadequate lighting quality, may make users feel ill. It is thus essential to design an appropriate lighting environment for occupants to be more comfortable and healthy, both physically and mentally. Moreover, the occupants are best able to decide whether a workstation is comfortable for them or not. Inadequate lighting design causes stress, which can trigger disease or impede biological function. However, the negative stresses that users feel are relatively slight and may not be noticeable to them. Therefore, the three main mental reactions ascribed to lighting are “activation, arousal, and stress” (Rice, 2003).

Lighting designers implement standards of illuminance for buildings because each different task has a specific luminosity rate established by IEQ guidelines, while visual perception varies with age, individual factors and parameters of the luminous environment. The spectral spreading of light sources is a significant element of IEQ, with colour temperature and rendering index used together to designate the temperature and spectrum of light sources (Steffy, 2008).

Hanford and Figueiro (2013) address the effects on mood and performance of spectral distribution of lighting, illuminance levels and lighting design. Abdou (1997) provides an empirical review of the importance of light quality in the physical environment, which relates to comfort, wellbeing and performance, emphasising the importance of lighting comfort and performance when predicting occupants morale. Reinhart (2013) reviews the association between people's daily patterns of activity and exposure to light, especially "the role of blue light in melatonin suppression", arguing that the benefits of lighting for building users should be a focus of concern in engineering practice. Illustrating luminous environments in design, such as daylight glare possibility and daylight metrics, is helping to conceive and design high quality lighting environments. Therefore, classrooms should be designed to meet every teacher's needs at all education levels. Generally, strong light and bright colours make users feel happy and comfortable (Ocvirk et al., 2009). An attractive option for classrooms is installing fluorescent lighting all-round the room to make the space brighter; ensuring a good level of illumination throughout classrooms, rather than pointing light on desktops, may have psychological benefits by creating a positive environment for students and teachers to perform their tasks (John and Timothy, 2005).

Occupant behaviour is considered to play one of the most important and complicated roles in determining the quality of the light environment. Nicol et al. (2006) explored the effects of daylight and blinds on lighting conditions as related to occupant comfort. They concluded that occupants who were able to control daylight levels were more comfortable than were those without access to daylight. However, the illuminance levels were not adjusted properly in response to exterior lighting conditions. They also found that employees preferred bright lighting of about 100 foot-candles at their workstations. A later experiment by Aries et al. (2010) found that when occupants had greater control over lighting conditions they appeared to show improved mood.

The orientation of windows produces clearly several of control responses, due to wind direction and solar radiation. Window control also depends on many other factors, such as outside temperature, season of the year, time of day and type of building (Zhang et al., 2010). Bessoudo et al. (2010) report that glazed southern facades, having greater exposure to sunlight, had a greater need of shading devices and that more blinds were used to avoid glare problems than on the northern side, indicating that an excess of direct sunlight caused users discomfort. Poor design and the heavy use of glass in elevations, without considering the building's orientation and solar attitude, causes annoyance for the occupants and leads to the increased use of blinds. This reduces daylight and so increases the use of artificial lighting, which in turn will increase energy consumption and CO_2 emissions (Barrett and Zhang, 2012).

The complexity of lighting quality is addressed in many studies by glare analysis. Winterbottom and Wilkins (2009), for example, report that the amount of daylight inside classrooms, governed partly by the use of window blinds, affected visual comfort, especially in viewing projected media. They conclude that illuminance levels in the 90 classrooms measured were too high and that the composition of lighting features and glare created varying conditions, which impaired the learning process. O'Connor et al. (1997) argue that windows are designed to provide views and to control glare; they admit daylight, which often delivers better illumination, maximizing comfort and performance. Correspondingly, Newsham et al. (2009) found that the presence of windows increased the accessibility of outside views and predicted the comfort of occupants with lighting. This study also identified strong associations between overall IEQ comfort, lighting comfort and job stress.

Daylight may affect teacher performance and student outcomes positively, although this influence is complicated by the diversity of daylight conditions that apply in practice. Characteristics of daylight glare and solar heat gain may affect occupants negatively, while views and dynamic lighting spectrum may have a positive influence (Evans, 2006). Daylight through windows with sunshades enhances views and contact with nature, which are associated with positive mood, less stress and improved job performance (Heerwagen, 2000). Hathaway (1995) argues that the use of natural light could affect performance in school. It has been clearly shown that the visual environment is one of the most important variable in learning, affecting class attendance and performance.

Several studies have confirmed the benefits to occupants of daylight and access to exterior views, finding that teachers were happier when they had the ability to control their lighting environment. Further, an appropriate level of lighting enhances performance, raises morale and saves energy, while bright light can reduce seasonal depression (Rice, 2003), although overly intense sunlight can create a painful glare for both teachers and students, especially during the summer (Lewy et al., 1980). In the literature reviews, Aries et al. (2010) found “limited statistically well-documented scientific proof” of the values of daylight on health and wellbeing and that daylight can reduce depression.

Controlled daylight and suitable artificial illumination need to be taken into account in classroom design, because lighting is critical to the quality of learning. Insufficient lighting control influences health and wellbeing and may cause many problems including eyestrain, muscular pain and increased body temperature, with negative consequences for students’ and teachers’ performance (John and Timothy, 2005). Conversely, many studies have shown that access to daylight and fresh air improve health, comfort and performance (Gordon, 2010).

In *The Lighting Handbook* (DiLaura et al., 2011), the Illuminating Engineers Society of North America provides standards and recommendations for lighting design in different building types and spaces. The measure commonly used for lighting design in workspaces is horizontal illuminance. Another important factor that defines the quality of lighting is the luminance ratio between the brightest and darkest points in a scene (Reinhart, 2013). A minimum illuminance level is usually required for safety purposes, while maximum level is limited by energy saving codes. However, designers rarely impose a specific illuminance level; instead, they provide accessibility and flexibility for building users to enhance their own comfort in ways suitable to that workplace. Heschong and Group

(2007) warn that artificial light contains ultraviolet rays that can cause fatigue, eyestrain and headaches, but that daylight can also negatively affect the comfort, performance, health and wellbeing of users, by forcing the eye to adapt very quickly to different light intensities, which is not only stressful and disturbing but also possibly damaging to the eyes.

2.3.4 Acoustic quality

The acoustic environment is related to “sensitivity of human hearing” to sound pressure waves. The quality of the sound environment is governed by several physical parameters, which include the characteristics of the space or room and physical properties of the sound. Sound is identified by the sound-pressure level and by sound frequency. Although hearing differs by age and individual, sound reverberation curves allow a signal with sound energy at many frequencies to be transformed to a sound level is based on human hearing (Chang et al., 1999).

Acoustic comfort is defined as “a state of contentment with acoustic conditions” (Navai and Veitch, 2003). The acoustic comfort is affected by such physical room characteristics as sound absorption, insulation and reverberation time. Factors affecting occupants’ comfort with the acoustic environment include “the sound frequency, the level of background noise, the transmission of sound between spaces and the reverberant properties of the enclosure”. The perception of noise conditions has a subjective component, so people may perceive a certain environmental noise as annoying even though its measurable parameters do not exceed the standard levels (Wallenies, 2004; Miedema and Vos, 2004).

Acoustic quality has a complicated association to comfort, health and behaviour. Linguistic interruptions, conversations and background noise interact to determine a comfortable acoustic environment. Balazova et al. (2008) explored the effect of the physical environment on office occupants, finding that eliminating audible office noise and intelligible speech and reducing the background noise levels resulted in no change in occupants’ preferences. This indicates that individual perceptions of the noise environment vary as to the relative importance of the effects of the background noise levels and noise distraction on conversations. Mackrill et al. (2014) provide another example of the relationship between background noise and comfort. They found that when participants listened to audio clips, various interventions had significantly different effects on relaxation levels. The researchers designed masking sounds using natural audio clips of birds and running water, which were found to increase levels of relaxation and comfort. The results of these two experiments suggest that individuals' responses to background noise are determined not only by their perception of sound but also by physiological mechanisms.

Indeed, other studies have reported individuals' survey responses to noise exposure, showing that the human perception of noise conditions may be affected by both personal and external factors. Classroom acoustics will affect educational outcomes, especially if speech communication has a critical effect on the learning process. This is because acoustic factors influence three aural communication channels that are necessary for classroom learning: "teacher to student, student to teacher and student to student" (Whitlock and Dodd, 2008).

An imperfect acoustic environment in a classroom will reduce the quality of speech communication, impairing students' performance and causing teachers to suffer from tiredness. Unwanted sound is difficult to ignore if it is not only louder but also appears clearer and more audible. Furthermore, students and teachers in noisy rooms tend to rise their voices to make themselves heard, thus further increasing noise levels, especially during group work (Tiesler et al., 2015). All such noise interferes with communication during lessons, interrupts the learning process, causes a loss of concentration, reduces task persistence, promotes error and raises the blood pressure of teachers and students who are exposed to the uncomfortable acoustic environment (Davies and Lee, 2007). Realyvásquez et al. (2016) found that noise directly affected psychological parameters, thus indirectly affecting employee performance.

Ronsse and Wang (2013) compared the effects of quiet rooms, reverberation time and binaural room features on students' reading and language scores. They report that quieter rooms with better "binaural frequency distortion" were associated with higher scores. Their study suggests that the degree of "binaural frequency distortion" caused by sound pressure energy offers a better measure of acoustic environmental quality in classrooms than simple reverberation time.

Certain specific properties of background noise have been shown to affect occupants' performance. Mak and Lui (2012) used a questionnaire survey to evaluate workers' comfort in office buildings. Most participants were annoyed by conversations and ringing phones, although background noise and the sound of closing doors were found to be the main sources of noise measured as above average, while all of these factors affected the quality of the work environment and performance. Finally, occupants under 45 years of age reported less acoustic disruption of their performance than did older employees.

Noise with strong tonal properties also affects comfort with IEQ. Ryherd and Wang (2008) found that the sound pressure of background noise with different tonal criteria generated various levels of noise in office buildings. However, respondents' comfort could not be predicted, even by using similar metrics of acoustic design, such as room and noise criteria. The findings showed a mismatch between occupants' responses and the principal model of acoustic comfort.

Acoustic quality in US schools was reported to be limited by the high cost of controlling it, especially the noise emitted by HVAC systems (Serra and Biassoni, 1998; Pinho et al., 2016). In educational environments, the perceived loudness of background noise should be less than 50 dBA to allow clear and normal speech communication, while reverberation time should be in range 0.8 to 1.0 seconds for normal listening and theoretical classes. Acoustic comfort is also associated with thermal sensation, which has an equivalent effect. For example, a temperature increase of 1 °C has almost the same influence as a change in noise level of 2.6 dBA (Pellerin and Candas, 2004).

The acoustic design standard for schools is ANSI/ASA S12.60-2010/Part 1 (American National Standards Institute [ANSI] et al., 2010), which recommends classroom maxima of 35 dB background noise and 0.60 seconds reverberation time, averaged over the frequencies of 500, 1000 and 2000 Hz.

2.3.5 Classroom layout and arrangement

The availability of space in a room affects occupants' comfort, performance and achievement. Evans (2006) reviewed the literature on the relationship of crowding with occupants' comfort and behaviour, concluding that increased occupant density is associated with higher levels of social exclusion and aggression. The results of this study suggest that occupant density is a better predictor of performance than class size. May et al. (2005) investigated the behaviour of receptionists in various workstations and found that those with less space were less comfortable with the available amount of space and often arrived late at work. Lee and Brand (2005) used statistical modelling to examine the relationship between comfort and workspace among 215 employees of five companies, concluding that those enjoying an appropriate size of space had better job performance.

Spatial layout and arrangements regarding visual privacy and adjacency are important determinants of employee performance. Typical school building designs and classroom layouts can reflect specific understandings and philosophies of educational vision in different cultures and countries (Blackmore et al., 2011). Classroom furniture is also considered to have a strategic role in facilitating learning styles and academic methods: "Innovative visions of how students learn properly with various methods to enhance this opportunity are changing how furniture assists the learning experience" (Felix and Brown, 2011). Furthermore, modern teaching technology can be integrated with classroom features including seating, tables and other furniture, so that an environment that is more flexible and adjustable to each teaching style may contribute to enhancing the quality of learning spaces (Blatchford et al., 2011).

Maxwell et al. (2007) established a rating scale to highlight the importance of the physical classroom environment in providing higher learning opportunities. The tool can be used to assess the comfort of teaching areas and to support access to spaces which would help to improve learning outcomes. The study concludes that a high quality of physical environment is beneficial for students and teachers and that the physical arrangement of a classroom is important for successful learning. Tanner (2008) employed the Design Appraisal Scale for Elementary schools (DASE), consisting of observational tools to determine the varying effects of classroom design, daylight and views on student and teacher performance. While Maxwell's (2007) tool considers many features of the classroom itself, DASE takes account of the whole school and its external environment to generate a background image of students' experience.

Castellucci et al. (2010) cite the work of Cornell (2002), Milanese and Grimmer (2004) and Chung and Wong (2007), highlighting various important elements that are used to assess learning quality in the classroom environment. These are *functionality*, including flexibility, mobility, safety, comfort and health; *usability*, including ease of use, prevention of accidents and optimization of use; and *aesthetics*, which determines whether a design is attractive to use. Classroom layout and the use of furniture are also considered major issues in spatial arrangement. Bissell (2004) lists classroom layout as a significant consideration for designers because a more flexible and adaptable design allows the teacher to adjust the arrangement of the classroom in order to perform various curricular activities and lessons. The flexibility to create a more favourable and comfortable environment can also maximize teacher comfort and the academic achievement of students.

It is important to consider the furnishing and functional needs of each classroom. Zunde and Bougdah (2006) suggest that general teaching spaces should be designed for simple furniture and functionality, whereas spaces with heavy or technical equipment need to be specifically designed. There are several guidelines for classroom layout, such as those of the General Service Administration and the National Association for the Education of Young Children, which make recommendations relating to the capability and safety of classroom environments. These recommend access to the outdoor environment and an average floor area of 2.1 m^2 per student and teacher (BB 102,2008). The regulations also indicate the types of materials and finishing of classroom floors.

The proper selection of furniture makes classrooms more attractive and comfortable. Moreover, changing the learning space can affect teachers' and students' behaviour, morale, practices and therefore, learning outcomes (Oblinger, 2005; Flutter, 2006).

The design of classroom seating arrangements is based on many elements, such as furniture type, number of students, classroom dimensions and teaching style. The most common arrangement of desks is in rows, which can enhance learning but minimizes student interaction. In addition, many teachers indicate that the row arrangement creates a wide visibility for them to monitor and assess students, promoting easy classroom control (Savage and Savage, 2009). The rows should be broken by throughways that allow the teacher to walk easily around the classroom and check students' progress during lessons. It is important to create traffic patterns to insure efficacy of movement inside the classroom for the teacher and students, leaving emergency exits clear for unexpected accidents (McLeod et al., 2003; Muijs and Reynolds, 2005; Savage and Savage, 2009).

2.3.6 Biophilia and view

Biophilia is defined as "the inherent human inclination to affiliate with nature that even in the modern world continues to be critical to people's physical and mental health and wellbeing". It represents a distinctive emotional feeling that associates human beings with other living entities, both plant and animal (Kellert and Wilson, 1993). The measurement of biophilia involves the psychological dimensions of comfort and visual quality characterized by several parameters including luminance distribution, illuminance, glare, colour rendering, flicker rate and amount of light (EN 12464-1, 2002).

Kellert and Wilson (1993) list three main components of the biophilia concept with implications for varied design techniques that refer to attributes of experience. These are direct experience of nature, indirect experience of nature and experience of space and place. Direct experience of nature is associated with the greening and natural surroundings of the working space. It includes plants, water features and natural light. Landscapes with spreading trees, forested views and savannah-type settings are most often preferred to advance people's health and wellbeing (Edwards, 2006). Indirect experience of nature includes artworks which simulate natural life. Nature paintings are the most common analogues used. Paintings of landscaping features such as mountains, rivers, lakes and seas can help to create a feeling of nature in the indoor environment (Kellert et al., 2008). Finally, experience of space and place is a design criterion including psychological and physiological reactions to the spatial layout. It also indicates the reasonable depth and openness that users prefer, which primarily applies to of clumps of trees and wide vistas (Kellert, 2012).

Wilson (1986) argues that views of nature play a significant role in wellbeing because the human brain evolved in natural settings. Research has shown that employees with a natural view experience less job pressure, are more comfortable and recover from stressful situations more quickly (Heerwagen and Orians 1986; Leather et al., 1998; Heerwagen, 2000). Mackerron and Mourato (2013) offer evidence that people have higher levels of happiness and wellbeing in a more natural environment because views of nature can reduce stress, anxiety and tension and create a positive mood among occupants, consequently improving performance.

Psychologists theorize that nature has essential features that occupants associate with the ideal physical environment (Evans, 2006). Wells and Evans (2003) found that nature created a buffer to stress after controlling the stressful life events and socioeconomic status. They suggest that the mechanism involved may be social, in that access to nature and natural landscapes will generate opportunities for social activities, and that access to nature might improve concentration. In a study of 500 college students, Benfield et al. (2015) found that those having views of nature had higher course scores at the end of a semester than those with views of a concrete wall. The former also rated the performance of their classrooms higher than students in rooms without views of nature.

Several studies have suggested that bringing the natural environment inside and around school facilities and creating pleasing views have positive effects on the comfort and performance of both teachers and students. Orienting buildings to the environment and providing views of nature through windows appears to reduce stress and enhance the mood of teachers, who feel less frustrated and appear more patient than others who have views of buildings only (Kaplan and Kaplan, 1998; Heerwagen, 2003).

2.3.7 Look and feel

Colour is a visual sensation generated by the response to light. It involves every aspect of our lives and can enhance the beauty and drama of everyday events (Holtzschue, 2002). Colours are important to ensure efficiency in the workplace: *"Colour is one of the least studied aspects of the physical environment, but it nevertheless remains the topic of some of the most optimistic claims about morale and efficiency*" (Sundstrom, 1987, p. 751). The concept of aesthetics in classrooms is often related to the overall condition of the building, including its age, features, status and cleanliness. Earthman and Lemasters (2009) assert that school environments, which are considered newer, with adequate maintenance, are associated with better teacher performance and higher grades among students than inadequate environments. Similarly, a school case study by Brager and Baker (2009) found that students' test scores were significantly higher after their building had been renovated.

Aesthetic factors were found to have a less significant influence on users' comfort and wellbeing than other IEQ factors whose functionally affected them directly and its effect on performance was less evident (Lee, 2014). Colour also differs in its effects on people because everyone experiences colour individually. Reactions to colour schemes depend on culture, education and genetic factors. However, colour does appear to influence wellness and the mood of workers (Garris and Monroe, 2005). Therefore, appropriate workplace colours should be selected to ensure positive employee moods and elevate performance. An analysis of several studies has shown that the colour of the workspace has a major effect on workers' mood and comfort (Kamarulzaman et al., 2011). A good colour scheme can engender a sense of calm and comfort, thus having a positive psychological effect on a building's occupants (Kamaruzzaman et al., 2015).

Lighting and colour constitute a significant IEQ component that directly affects people's emotional state, either positively or negatively, and which may improve or impair performance. Colour is thus an important factor in designing the built environment. Warm colours such as red and orange can stimulate and activate users, while cool colours like blue and green are used for relaxation. A number of studies show that more errors were made by workers in white painted offices than in those with coloured decor (Wigg et al., 2009). The combination of colours and lightness can enrich environmental design. For example, blue interior walls in clothes shops are associated with favourable evaluations and are seen as more attractive than other colours, while soft, orange-coloured interior lighting has been found to reduce illness (Babin, et al. 2003).

Daggett et al. (2008) argue that classrooms should be decorated in a variety of colours based on "age, gender and activity", to reduce tedium and provide a richness of visual perception. Colour is considered an important feature in the physical classroom environment that can augment the quality of light and minimize the negative effect of lighting on occupants. A variety of colours in classroom reduces passivity, alleviates monotony and may stimulate students to learn well, while also increasing teachers' efficiency. The selection of an appropriate colour scheme in addition to good lighting and texture can create an enhanced learning environment (Daggett et al., 2008).

Environmental psychology has made important contributions to studies of classroom layout, occupant density and colour. Maxwell (2007) investigated the relationship of student outcomes with the physical classroom environment in terms of well defined spaces, concluding that the quality of the indoor physical environment could be interpreted as offering opportunities for challenge and sensual integration. Classroom décor plays an important role in creating a pleasing view and ensuring a comfortable environment; using many features such as mirrors with decorative frames can transform a wall and act as a focal point which can create an impression of more space (Sommer and Olsen, 1980). The effects of texture, colour and shapes in indoor design can lead to a positive feeling of wellbeing in the workplace and can influence users to act in specific ways. In addition, these elements can create a comfortable atmosphere that engenders emotional feelings such as happiness, warmth and relaxation (Nielson and Taylor, 2002).

2.3.8 Location and amenities

Health and wellbeing are associated with better transport connectivity and the accessibility of the workplace. Several studies have suggested that land use and transportation patterns affect occupants' health. The heavy use of vehicles contributes to atmospheric contamination, which elevates the risk of respiratory and vascular disease. Reduced physical activity including walking contributes to obesity, diabetes and associated illnesses. Time spent in traffic increases the risk of accidents and affects timekeeping (Frumkin, 2002). According to Haider et al. (2013), locating a workplace near to public transportation services may reduce fuel usage by 20 to 40%, while providing suitable walkways facilitates pedestrian access, helping employees to arrive safely at work. Rod et al. (2012) found that when users walked to and from public transportation, every kilometre walked per day reduced the risk of obesity by 5%, whereas it increased by 6% with each hour per day spent in a car, which also aggravated air pollution. Employees who regularly walk to work are less frequently sick and absent than their non-walking colleagues (Larsen et al., 2009). These health benefits indirectly help employees to perform better in the workplace.

Today's school buildings enhance a variety of learning and work environment experiences for students, teachers and administrators (Castaldi, 1994). Each classroom in a school building has specific physical characteristics and its quality can affect teachers' morale, health, safety and teaching ability, and thus the ultimate success of educational programmes (Kowalski, 2002; Buckley et al., 2004; Planty and DeVoe, 2005).

Vischer (2007) defines functional comfort in terms of the ergonomic enhancement of work performance, as related to tasks and activities. For example, functional comfort can be enabled by adequate lighting for screen-based work, ergonomic computer furniture and the provision of enclosed rooms for meetings and other teaching needs. The complementary concept of psychological comfort is based on the feelings of ownership, belonging and control over the workspace.

The quality of school facilities affects teachers' performance and comfort, which may influence their intention to stay in the profession or to leave their job. In both developed and developing countries, the importance of the quality of a facility is marked by its effect on teacher comfort (Schneider, 2002; Collie et al., 2012). However, communities and parents often have contrasting perceptions and expectations of buildings and other amenities within the education system. Tanner (2009) notes that the quality of school facilities is a strong predictor of teacher and student performance and behaviour, making it an essential prerequisite of academic success.

Overall, the physical indoor environment comprises a broad set of variables, some tangible and others not. Identifying and measuring all of these is a complex task, because there are many industry standards recommending different values of the various independent physical IEQ attributes. Empirically, these parameters are subject to widely varying responses in surveys of building occupants, indicating that there is no simple measure of comfort, but rather a broadly defined comfort zone for each attribute.

2.4 Weighting the Effects of IEQ Factors on Occupants' Comfort and Performance

A number of studies have examined the strength of the associations of occupant comfort and building performance with individual IEQ factors, such as thermal comfort, acoustic quality, air quality and visual comfort (Kim and de Dear, 2012). Some researchers have concluded that an enhancement of occupants' overall comfort does not correspond reliably to improvements in individual IEQ factors (Bluyssen, 2014; Humphreys, 2005). Others have found that comfort in buildings can be affected by factors not directly related to quantifiable components of IEQ, such as the ability to control environmental parameters (Frontczak and Wargocki, 2011; Schiavon and Altomonte, 2014). Studies by Bluyssen et al. (2011) and Veitch et al. (2007) concluded that the comfort of building occupants was also affected by variables such as view, amount of privacy, layout, cleanliness, aesthetics and furnishings. This section reviews the most recent comprehensive studies, including the findings summarized by Frontczak and Wargocki (2011), to determine which IEQ variables were the most strongly associated with occupants' comfort and performance.

Humphreys (2005) conducted a study concerned with occupants' evaluations of IEQ and overall comfort in 26 office buildings in five European countries: France, Greece, Portugal, Sweden and the UK. Measurements of air temperature, globe temperature, relative humidity, air speed, concentration of CO_2 in the air, illuminance and sound level were taken over a period of more than a year in work areas, while outdoor temperatures were obtained from nearby meteorological stations. At the same time as these physical measurements of IEQ parameters were being recorded, interviews were used to gather occupants' subjective assessments and evaluations of IEQ, using rating scales from zero to five for thermal sensation, thermal preference, humidity, air quality, light and sound. The survey responses denoted to the IEQ at the time of interview, allowing the researcher to compare both general impressions of building condition and detailed perceptions of a suitable indoor environment with physical measurements during both summer and winter seasons. The study found that individual aspects of comfort did not necessarily correspond to overall levels of comfort; rather, there was a weighted subjective rating process, whereby overall comfort was more strongly associated with thermal and air quality than with levels of lighting or humidity.

Lai and Yik (2007) investigated occupants' perceptions of aspects of IEQ in commercial buildings in Hong Kong, using face-to-face interviews and a three-part questionnaire. The participants were 548 end users and 66 building professionals, contractors and facilities management personnel. The first part of the survey asked about respondents' gender, job, purpose and duration of visits to the commercial buildings. The questions in the second section elicited end users' perceived comfort level with nine aspects of the facilities. Respondents were also asked to rate their perceptions of four IEQ factors: thermal comfort, air quality, odour and the noise associated with the air conditioning system. The final section asked them to rank the relative importance of these factors. The importance of IEQ factors as perceived by the respondents was determined using the analytical hierarchy process (AHP). Close examination of the ranking results supports the contention that subjective judgments of the importance of IEQ attributes varied according to certain psychophysical attributes, including personal experience, which in turn varied with gender, type of respondent, purpose of visit and duration of stay in the building. Overall, the user groups ranked IAQ as more important than thermal comfort, whereas both users and non-users considered air quality and acoustic quality as of comparable importance.

Also in Hong Kong, Wong et al. (2008) studied the indoor environmental conditions in typical air-conditioned offices with floor areas of 90 to 1200 m^2, finding that an occupant's acceptance of an environment depended on a number of environmental factors. Four basic components, namely thermal comfort, IAQ, visual comfort and acoustic quality were identified as determining an acceptable IEQ. The subjective evaluations of 293 occupants were elicited using a dichotomous scale of responses to yes/no questions of the form: "Is the thermal environment/indoor air quality/noise level/illumination level being perceived in the office environment acceptable to you?" The authors argue that the subjective assessment of an indoor environment can be used to evaluate acceptance of the IEQ. In particular, occupants' acceptance of the four basic parameters of IEQ were evaluated and correlated with the overall IEQ acceptance of the office environment. Thus, occupants' behaviour towards the operative temperature, lighting quality, CO_2 concentration and noise level were measured, along with overall IEQ acceptance. All four parameters were found to have significant effects on overall IEQ acceptance, with the ranking from most to least important being thermal environment, air quality, noise level and lighting.

Astolfi and Pellerey (2008) investigated IEQ in renovated school classrooms over a year, taking subjective and objective measurements of acoustic quality and using a questionnaire to elicit subjective evaluations of other environmental factors and their influence on overall IEQ. The purpose of the study was to determine which factors affected thermal, visual and indoor air quality and which environmental aspect was most closely correlated with perceived overall IEQ. The subjective survey investigated 51 classrooms, some of which had been acoustically renovated, while acoustic levels were also measured objectively in a sample of eight classrooms, selected to be representative of the 51 in terms of characteristics including volume. The survey, administered to 1006 students, included items on overall quality and on factors such as acoustic, thermal, indoor air and light quality. The results show that students perceived acoustic quality as having the strongest impact on their school performance, followed by visual, thermal and indoor air quality, and that they attributed most relevance to acoustic conditions in their overall quality evaluation. Acoustic quality was interrelated to speech comprehension, which was correlated to the speech transmission index, although the index did not reflect all of the other factors. Acoustic comfort was higher in renovated classrooms and one of the most significant consequences of satisfactory acoustics was an increased in concentration.

Lai and Yik (2009) explored indoor environmental conditions in typical public and private high-rise residential buildings in Hong Kong, assessing the importance of four aspects of IEQ and the performance of the buildings in respect of these attributes. The AHP method was used to analyse survey data collected from 563 respondents to weight the relative importance of the IEQ factors. Correlation analyses validated the results, which varied among buildings of different forms and between building users, who were differentiated within the questionnaire because users, having different experiences to environmental stimuli, were expected to have altered perceptions of the importance of IEQ factors. Length of residency in the building was also elicited. The second part of the survey concerned the perceived relative importance of the IEQ factors on a nine-point scale, while the final part elicited perceptions of these factors in the common space on a seven-point scale. The researchers minimized interview time to maximize full participation. They also observed whether common areas had openable windows or not, because this would directly affect ventilation and thus noise quality, thermal comfort and air quality. A post-survey quality check eliminated two-thirds of the collected data, leaving 32% of the data from private user groups and 34% from public buildings for use in the analysis. Residents of public buildings rated thermal comfort and noise as the two most important factors, although their performance was ranked lower than their importance. In contrast, the performance of air quality was the highest, but it was rated as the third most important factor.

Lai et al. (2009) investigated occupants' acceptance of residential IEQ through physical measurements and subjective surveys, using a multivariate regression model with the four IEQ factors of thermal comfort, IAQ, visual environment and acoustic environment. Individual interviews were used to elicit subjective assessments of indoor environmental conditions from 125 occupants of 32 typical residential apartments in Hong Kong, in the luxury, private, public and Home Ownership Scheme categories, selected to cover almost all indoor environmental conditions. Objective measurements were taken of seven IEQ parameters: indoor air temperature, radiant temperature, relative humidity, air velocity, CO_2 concentration, illumination and sound level, for fifteen minutes. To assess the environmental conditions in each of the rooms at the time of the visit, spot meter readings were taken of lighting level, CO_2 level, temperature, noise level and relative humidity. These enhanced the researchers' opportunity to identify potential problem areas, but were not used directly in the metrics created. Occupants' environmental acceptance was assessed by their responses to yes/no questions: "Is the thermal environment/indoor air quality/ noise level/illumination level in the residential environment acceptable to you?" In order to validate the responses, the researchers used a semantic differential evaluation scale for the subjective assessment of thermal comfort and IAQ, and a visual equivalent assessment scale for the evaluation of acoustic and visual comfort. The results show that operative temperature, CO_2 concentration, equivalent noise level and lighting level all affected overall IEQ acceptance. Based on the total responses, the most effective parameters were thermal and acoustic environmental qualities, while the least effective was indoor air quality.

Lee et al. (2012) used subjective and objective measurements to investigate the relationship between IEQ and learning performance in Hong Kong Polytechnic University teaching rooms, collecting data on air temperature, relative humidity, air speed, CO_2 concentration, sound level, horizontal illumination level, teaching activity in four classrooms and four large lecture halls, self-reported learning performance and perceived IEQ. All measurements were taken during teaching activities from 8:30 am to 10:30 pm, Monday to Friday, when data on class size, floor area class size were also recorded. The IEQ attributes were measured every 30 minutes during each class or lecture. In addition, outdoor air temperature and relative humidity were measured. A survey was administered during breaks to elicit subjective assessments of perceived IEQ on four parameters: thermal environment, IAQ, illumination and noise levels. Respondents were engineering students, who were invited to evaluate their own learning performance. The study used two IEQ assessment scales, a semantic differential scale to assess the thermal environment and overall IEQ, and a dichotomous scale in response to the question: “Is the thermal environment/ indoor air quality/ noise level/illumination level/indoor environmental quality acceptable to you?” Analysis of 312 responses showed that 195 of the 298 respondents accepted the indoor environment, that “214, 37 and 11 were not comfortable with one, two and three of the four IEQ factors respectively, that eight complained about all four features and that 28 had no complaints at all”. There were strong associations between the overall IEQ scores and the environmental parameters. Thermal comfort, indoor air quality and visual environment were of comparable effectiveness, while sound level was the major determining factor.

Cao et al. (2012) studied the relationships of subjective comfort and satisfaction assessments with objectively measured indoor environmental factors in office buildings, teaching buildings and libraries in Beijing and Shanghai during 2008 and 2009. The environmental parameters were CO_2, lighting and sound level, while thermal comfort was assessed by the PMV and PPD indices. Instruments were placed 1 m above the floor and each measurement was taken for 15-20 minutes, during which time the 500 occupants, aged 20 to 30 years, filled out questionnaires about the indoor environment to evaluate their comfort and satisfaction. Temperatures ranged from 16.6 to 30.3 °C and relative humidity from 15% to 75%, with a mean value of 45%, while CO_2 concentration averaged 275-2360 ppm, illumination intensity was between 140 and 2150 lux and sound levels were 39-56 dB. The analysis indicated that the factors having the strongest effects on satisfaction and overall comfort respectively were thermal comfort and acoustic quality, and luminous environment and air quality.

Barrett et al. (2015) assessed the impact of IEQ on students' learning, by collecting data from 30 schools with a wide range of architectures, building age and sizes in three areas of the UK. Ten schools were in Blackpool, where student poverty was high, ten in a rural part of Hampshire and ten in an area of outer London with high densities of housing and population. They ranged from small, mixed-year-group village schools to large urban ones, giving the sample a wide diversity of physical characteristics. Lighting levels, CO_2 levels, temperature, noise levels and relative humidity were recorded five times in each of the rooms to assess IEQ. These measurements allowed the researchers to identify specific problem areas. Surveys and interviews were used to measure the performance of students in the same rooms, based on their grades in reading, writing and maths at the start and end of the academic year. A multi-level linear regression model allowed data collected from groups having the same environment to be more closely correlated than from students in different classrooms. It was found that light, temperature and air quality had significant effects on learning outcomes and that large windows did not usually maximize learning benefits.

Awang et al. (2015) investigated users' perceptions of IEQ and its effects on teaching and learning in a secondary school in Selangor, Malaysia. Objective and subjective data were again used to identify the elements of IEQ that caused discomfort and health problems for teachers, students and other staff members and to explore their effects on teaching and learning. Objective measurements of airflow speed, temperature and humidity, all of which affect thermal comfort, were recorded at several locations in the learning environment, while questionnaires on IAQ, acoustic quality, visual comfort, thermal comfort and the effects of IEQ on teaching and learning were administered to occupants to identify weak aspects of IEQ, health symptoms and how IEQ might influence the teaching and learning process. The perception of IEQ was assessed on a seven-point Likert scale from 'very strongly disagree' to 'very strongly agree'. Objectively measured IEQ parameters all fell outside the ASHRAE standard range, although the survey results showed that the highest percentage of agreement with IEQ factors corresponded to the highest level of comfort with these factors. Health symptoms reported by participants included tired eyes, stress and fatigue. Among the main IEQ parameters found to affect teaching and learning, sound quality had the strongest effect, followed by IAQ, then thermal comfort and visual comfort.

Figure 2.4 maps the strength of the effects on performance of these four attributes as reported in the above studies.

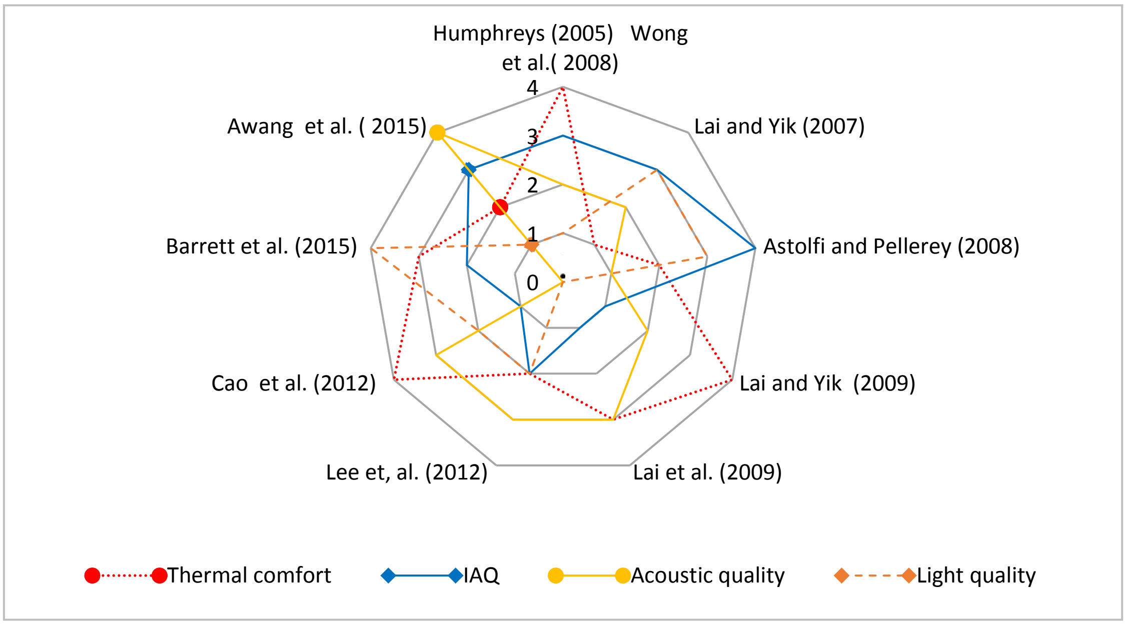


Figure 2.4: Weighted effects of physical environmental factors on performance; higher numbers indicate stronger effects.

Other IEQ variables, such as layout and arrangement, biophilia and view, look and feel, and location and amenities, showed a similar effect on comfort but were only weakly associated with performance. Heerwagen et al. (2004) also point out that users will often try to improve spaces with visual materials; hence the importance of decoration. All of these secondary factors are difficult to evaluate, leading Barrett et al. (2015) to suggest that "expert judgement" should be employed to incorporated them into a comprehensive assessment.

2.5 Overview of Educational Buildings in Saudi Arabia

The quality of Saudi school buildings is not adequate for the educational needs of a rapidly increasing population and many school buildings were obviously constructed too hurriedly to cope with the rising numbers of students and users. This has become a critical issue because most Saudi nationals in the workforce lack the relevant experience, while expatriates employed to support the Saudi educational system lack the necessary cultural knowledge (Al Megren, 2008). The Saudi public educational system today comprises around thirty public and private universities, large numbers of colleges and other training institutions and more than 35,000 schools throughout the country. All students in Saudi Arabia receive schoolbooks and health services free of charge and there are no educational fees. Over a quarter of the national budget is assigned to improving educational quality by providing professional training (MoE Report, 2017).

School buildings in all parts of Saudi Arabia are built to a standardized design consisting of a central shaded courtyard linked to all classrooms by 2.5-metre wide corridors on each side of the building. These classrooms use a simple design of doors and windows with an HVAC system to control ventilation. The shaded space block design includes strips of glass which allow light and ventilation to flow through the building. This is an architectural system that eliminates the need to use central air-conditioning by using a system of “louvered openings” (Fernandez et al., 2007, p.341). Saudi school buildings have three stories, the ground floor usually being occupied offices and laboratories, while the upper floors house the classrooms, which average 56-60 m^2 in floor area. Schools are classified as small, medium and large, accommodating 100-300, 300-600 and more than 600 persons respectively (SCDSI, 2017).

A recent literature review suggests that there is a valuable opportunity to conduct research focusing on the condition of school buildings in Saudi Arabia, to determine whether the influence of the environmental conditions is consistent with national educational policy (Alsubaie, 2014). Among the few published studies which have investigated the condition of school buildings in the Kingdom, only two, by El-Sharkawy (2014) and Alsubaie (2014), have measured and evaluated the indoor physical environment objectively and both were limited to indoor air quality.

El-Sharkawy (2014) studied 16 randomly selected elementary schools in the Eastern Province, 12 of which were housed in government-built school buildings, while the other four were in rented buildings. The parameters of IAQ measured in each school were total suspended particulates (TSP), temperature, relative humidity and concentrations of nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO) and sulfur dioxide (SO_2). These parameters were recorded twice during each school day, between 8 and 9 am and between 10 and 11 am, with readings taking 15 to 30 minutes at each measuring point. Temperature was recorded as 26-26.5 °C during the first period, rising in the late morning to 27-27.4 °C, which exceeds the values recommended by ASHRAE55. The average values of air parameters inside schools located on streets with moderate traffic activity were TSP = 4.0 mg/m^3, SO_2 = 0.06 ppm, NO_2 = 0.02 ppm, CO = 3.2 ppm and benzene = 0.4 ppm, while an average CO_2 concentration of 1600 ppm was measured inside schools on low-activity streets. Statistical analysis of the data using the *t*-test indicated a strongly significant difference for CO and SO_2 ($p \leq 0.005$), a slight significant difference for benzene ($p = 0.05$) and no statistically significant difference for any of the other air pollutants ($p > 0.05$). The results of the El-Sharkawy study indicate that the average values of TSP, NO_2 and CO inside all of the schools were within the air quality guidelines, whereas all average recorded CO_2 levels and about half of the SO_2 and benzene values were higher than these recommended values. The author concludes that it is essential to enhance IAQ inside classrooms by improving the efficiency of mechanical ventilation and HVAC systems.

In the same year, Alsubaie (2014) investigated CO_2 concentration and ventilation rates in a randomly selected sample of 26 governmental primary schools and 10 rented schools, all built before 2008 and located in urban areas of the Eastern Province. The data were collected during the summer, while normal teaching activities were underway in the 144 classrooms selected for study. The researcher took CO_2 readings five times in five different positions in each classroom, between 9:00 am and 12:00 noon, then calculated average CO_2 values. The data were analysed statistically using SPSS and the t-test was used to identify differences in average levels of CO_2 between the different types of school, significant at $p < 0.05$. The results of the Alsubaie study show that only four of the selected schools (11% of the total) had adequate ventilation, as indicated by the fact that mean CO_2 values in almost 90% of schools exceeded the value of 1000 ppm recommended in the ASHRAE guidelines. In detail, the average CO_2 levels recorded in governmental schools and rented buildings respectively were 1250 ppm and 1520 ppm at 9:00 am, rising to 1810 ppm and 2030 ppm at noon.

Therefore, the present research addresses a significant need to investigate the topic of indoor environmental quality in Saudi school buildings, not only to determine the precise environmental conditions but also to understand their effects on teaching and learning outcomes and to raise awareness among communities and school authorities regarding the significance of ensuring that the environmental conditions in classrooms meet the strict requirements of ensuring the health of school users and the safety of their environment.

2.6 Indoor Environmental Quality Framework

This research has reviewed a number of studies to develop and test a model of the effects of IEQ on teacher performance. Numerous previous studies have shown that improvements in the IEQ of different types of building (commercial buildings, offices, schools and homes) can increase economic returns by enhancing work performance, reducing absences and cutting healthcare costs (Frontczak et al., 2012).

Performance is defined as a multidimensional concept comprising task and contextual performance. Task performance is an individual's proficiency in performing specific activities, which contribute towards improving an organization's output, while contextual performance refers to activities that maintain social, organizational and psychological environment, thus improving work procedures in the pursuit of organizational goals and objectives. The concept therefore covers both the operational and economic aspects of excellence, including productivity and profitability, which are characterized as "quality, speed and flexibility in efficient and effective actions" (Tangen, 2005).

Performance measurement is the process of assessing the achievement of goals and objectives in terms of specific criteria. Teacher performance criteria are used to quantify the efficiency and effectiveness of class activities, in order to increase the visibility of the quality and progress of teaching tasks; they help to justify, manage and evaluate quality and performance at the operational level (Grünberg, 2004). Harri and Sass (2011) list some of these criteria as: "communication skills, enthusiasm, intelligence, knowledge of subject, strong teaching skills, motivation, works well with team/department and the principal, contributes to non-class activities", all of which may be affected by the conditions in which a teacher works, including all aspects of IEQ.

Comfort is defined as a state of relaxation and a pleasant feeling that affects wellbeing and health. Oseland (1999) classifies the components of environmental comfort as physical conditions (air quality, light, noise, temperature, etc.), space design (layout, orientation) ergonomics (tasks, workstation and control) and aesthetic factors (colour, texture). After a comprehensive review of the literature, Schneider (2002) identifies the six main structural and cosmetic factors that affect learning outcomes as IAQ; ventilation and thermal comfort; lighting; acoustics; building age; school and class sizes. Architectural designers should understand the criteria of building design that influence the quality of the indoor physical environment and occupants' comfort and wellbeing. The IEQ parameters which are affected by designers' decisions include acoustic conditions, air quality, architectural details, controllability, ergonomics, lighting conditions, maintenance, space planning, thermal conditions and ventilation qualities (Lee and Guerin, 2009; Vischer, 2007).

Among the many factors, which influence teachers' job performance are teaching methodology and techniques and personal characteristics, which are not included in this study, and aspects of the physical environment of the classroom such as temperature, air quality, light, ventilation and noise (Ferris, 1998). Wargocki (2008) found a relationship between poor IEQ conditions and

SBS, and between good IEQ and improved health and performance. Becker et al. (2007) showed how improving buildings' IEQ increased occupants' comfort and performance. Hancock and Stevenson (2009) found that poor indoor environments could cause dizziness, throat irritations and other health problems, which could impair occupants' comfort and performance. While these studies seem to establish a relationship between IEQ and occupants' wellbeing, there is nonetheless a need for deeper investigations of these issues (Singh et al., 2011).

The investigation of the relationship between the indoor physical environment and performance is complicated by how difficult it can be to quantify the benefits of developing occupant health and performance in terms of financial savings (Sakellaris et al., 2016). The research framework adopted here reflects recent studies which assert that the classroom should be an environment where "people want to be, not a place they have to be" (Cornell, 2002, p. 41). The condition of the classroom may weaken users' morale, comfort and performance in the learning process, thus diminishing student achievement (Earthman and Lemasters, 2009).The outcome variable for this study is based on the assumption that teachers who are more comfortable with their indoor physical environment will perform better and so improve the quality of their students' learning.

Using structural equation modelling, Wells (2000) found that greater comfort with the physical environment predicted higher performance among teachers and others. Therefore, this study suggests that the quality of the indoor physical environment in educational buildings is related to teacher performance. This concept is tested using the assessment model whose development is reported in Chapter 5. In the conceptual framework for this study, shown in Figure 2.5, the arrows represent the systematic relationships by which various indoor environmental factors will affect a teacher's performance.

The building of the framework was guided by the above literature review. These factors assisted in the collection of research data, the design of the survey questionnaire and the determination of the appropriate instruments and sensors for the various elements, as detailed in Chapter 3, to explore the relationships of the indoor physical environment with comfort, wellbeing and performance by means of the assessment model.

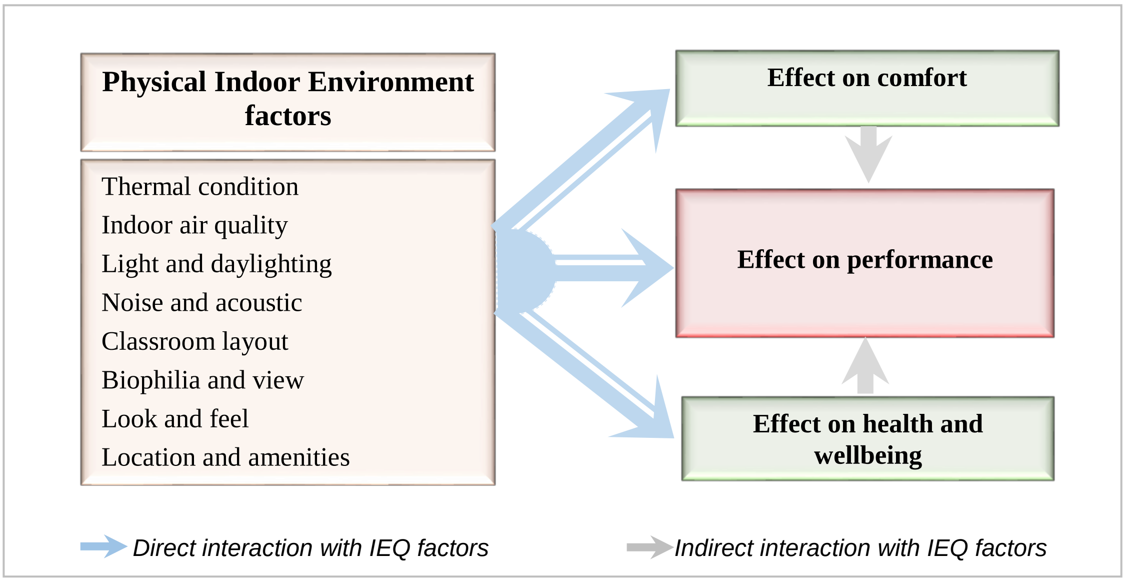


Figure 2.5: Conceptual framework

In summary, this literature review has addressed most of the physical aspects of the indoor environment that directly or indirectly affect comfort, wellbeing and performance of a buildings' occupants, including teachers. These effects operate individually and in combination with other parameters, which makes the study of indoor environmental quality particularly complex. According to Schneider (2003) and Buckley et al. (2004), half of teachers surveyed in Chicago and Washington DC reported problems with indoor air quality and almost a third suffered health problems that affected their performance negatively.

In addition, inadequate IEQ conditions have been found to influence teachers' performance differently by impairing the teaching environment. Conversely, controlling physical indoor environmental conditions such as temperature and ventilation improved employees' performance by 6.5% (Wyon, 2004). Table 2.2 summarizes the effects of inferior indoor conditions on teachers' performance.

Table 2.2: *Indoor conditions negatively affecting teachers' performance*

IEQ Factors	Influence on	Negative consequences	References
Thermal comfort	Teachers' perceptions, cognition, moods, motives, concentration, mental acuity, attention and dual task achievement	Discomfort, increase in aggressive behaviour, inability to concentrate in classroom, increased metabolic rate	Wargocki and Wyon, 2007; Mendell and Heath, 2005; Sicurella and Evola, 2012.
IAQ	Health and wellbeing, fresh air quality, increased containment, odour and gaseous emission (CO_2, CO, SO_2)	Dissatisfaction, tiredness, difficulty in concentrating, impaired cognitive performance	Kielb et al., 2015; Bako-Biro et al., 2012; Edwards, 2006; Shendell et al., 2004.
Light quality	Quality of lighting, visual acuity, brightness, control glare, attractiveness of decor, mood, mental function, memory recall	Depressive mood, inability to concentrate, impaired cognitive performance	Hagerman et al., 2005; Heschong, et al., 2002.
Acoustic quality	Acoustic comfort, student-teacher interaction, speech communication	Tiredness, impaired cognitive performance, feelings of ineffectiveness	Klatte et al., 2010. Trombetta et al., 2008; Lercher, 2007; Davies and Lee, 2007.
Visual comfort	Visual comfort, interaction with the natural environment, visual exposure	Depressive mood, impaired cognitive performance	Sanoff,2009; Heerwagen, 2000.
Layout & arrangement	Furniture arrangement, teachers' movement patterns, interaction with students, teachers' emotions	Negative teaching behaviour, teacher attitudes, demotivation	Jamieson, 2003; Lang, 2002; Maxwell et al., 2007.
Look and feel	Psychological comfort, class beauty, appeal, attractiveness, behaviour, mood and wellness	Poor relaxation, focus and concentration on tasks, mood swings	Kuller et al., 2009; Garris and Monroe, 2005; EN 12464-1, 2002.
Location and amenities	Mental attitude, class attendance, performance	Impaired learning, poor academic performance, reduced effort	Hathaway, 1995; Corcoran et al., 1988.

The many studies which have examined the health implications of IEQ factors on occupants' wellbeing indicate that the condition of IEQ in the classroom has both physical and psychological influences on teachers' performance (Horr et al., 2016). Table 2.3 summarizes the implications and complexity of the relationships between IEQ conditions and occupants' wellbeing.

Table 2.3: *Effects of physical indoor environmental factors on wellbeing*

IEQ Factors	Health impacts (physical and psychological)	References
Thermal comfort	Fever, chills, fatigue, dizziness, nausea	Balazova et al., 2008; Wargocki and Wyon, 2013; Mendell and Heath, 2005.
IAQ	Asthma, chest tightness, respiratory allergy, fever, headache, eye/nose/ throat irritation, fatigue, itchy skin	Fisk et al., 2007; Kajtar et al., 2006; Mendell and Heath, 2005; Daisey et al., 2003.
Light quality	Headache, dizziness, nausea, fatigue, eyestrain, aches	Alrubaih et al., 2013; Heschong et al., 2002; Heschong, 2007; Becker et al., 2007.
Acoustic quality	Stress, headache, fatigue	Tiesler et al., 2015; Navai and Veitch, 2003.
Visual comfort	Depression, stress, headache, fatigue	Leather et al., 1998; Heerwagen, 2000.
Layout and arrangement	Stress, headache, fatigue,	Milanese and Grimmer, 2004; Bissell, 2004.
Look and feel	Stress, depression, headache, fatigue	Garris and Monroe, 2005; Nielson and Taylor, 2002.
Location and amenities	Depression, stress, headache, fatigue, demotivation.	Buckley et al., 2004; Kowalski, 2002.

2.7 Conclusion

The above literature review has identified eight physical factors which strongly affect IEQ and—in the context of the classroom—teacher performance, the most important being thermal comfort, indoor air quality, acoustic comfort, lighting and class layout. Various studies indicate strong correlations between these factors and teacher performance. The conceptual framework adopted for the present study seeks to facilitate an understanding of the associations of each of these environmental factors with teachers' comfort, wellbeing and performance, while recognizing the existence of significant and intricate interrelationships among these independent variables. Indeed, the results of the review indicate that the IEQ factors identified here should be studied together in order to investigate the network of relationships comprehensively and to evaluate the contribution of each individual factor; for example, the effects of ventilation flow rate on CO_2 concentration and on comfort level need to be examined very carefully.

Comprehensive studies of the indoor physical environment were conducted to explore the associations among IEQ variables and to determine their most significant effects on comfort, wellbeing and performance. This endeavour is complicated by the fact that definitions of comfort in the literature have broad theoretical, social and psychological dimensions including physical wellbeing and personal health, while performance is defined in terms of various dimensions that are difficult to measure tangibly.

Chapter 3

Research Design and Methodology

The previous chapters have detailed the knowledge of IEQ factors on which this research is based, including the main findings of the review of literature. The focus in this chapter is on the research methods used, the research design strategy, the basis on which they were preferred and their appropriateness. Research methodology can be defined as the fundamental processes of logical thought that are applied to generate the general blueprint by which the researcher plans to fulfil the aim and objectives of the research.

3.1 Introduction

Research methodology concerns the approach taken to solve a research problem systematically (Kothari, 2004). It establishes the general plan by which the aim and objectives of the research are to be achieved (Fellows and Liu, 2015). The concept of research itself may have many meanings for different individuals, but some of its main principles are constant for many researchers and authors. Research is a process of enquiry and investigation guided by scientific systems and methods (Denzin, 1978). The main purposes of research are to learn and gain knowledge, which can then be used in generating a theory, framework or model, to identify and clarify phenomena, or to propose solutions to problems or resolutions to unsolved inquiries (Chadwick et al., 1984). Creswell (2003) explains that a theory consists of interconnected variables, descriptions and propositions, which together provide a methodical approach to specifying the relationships among the variables, in order to clarify characteristic phenomena.

In this research, the data were collected by means of a specific case study, comprising the quasi-experimental recording of objective physical measurements and the use of a survey to elicit subjective data. The case study, which is considered an effective strategy to gather detailed research data, is initiated by the application of deductive techniques to the research problem and results in an inductive logical procedure (Saunders et al., 2015).

The significant characteristics of the site chosen for the case study are that all of the buildings on the site were of the same basic design and that they nevertheless differed in orientation, which the teachers had diverse backgrounds and that similar classroom furniture and equipment were exposed to different indoor environmental conditions. Many physical indoor environmental factors such as temperature, humidity, airflow speed, illuminance, sound level and carbon dioxide concentration were measured in the classrooms and a fifteen-minute questionnaire survey was completed at the same time as the environmental parameters were being recorded. This chapter explains the choice of methods used to explore the relationship between IEQ parameters in these academic buildings and the performance of academic staff members (teachers, instructors and professors) within their classrooms. The chapter reviews references to IEQ methods in the literature, delineates the characteristics of the buildings under study, explains the structure of the questionnaire and describes the IEQ instruments. It explains how the data were gathered in order to build a model to investigate the association between the indoor physical environment and performance, in line with the research aim and objectives.

3.2 Research Methodology

Research methodology is a systematic way to discover the proper solutions to specific problems based on logical relationships between different elements and terms (Saunders et al., 2015). The primary objective of theory is to answer questions of what, how, when, where, and why (Bacharach, 1989). Creswell (2003) defines a research methodology as a logical development of study process used to generate theory that leads to the establishment of techniques to answer the research question. Research methodology is described as the methodical and formal specification of the procedures used to uncover and interpret new facts and relationships (Waltz and Bausell, 1981).

The scope of the term ‘research methodology’ includes several areas of knowledge required to construct a study, such as the design strategy, the underlying philosophy and the research methods used, detailing the suitability of the methods to be implemented. This methodology chapter therefore explains the choice of a philosophical stance and an appropriate approach to addressing the research questions, followed by different techniques for collecting and analysing the data. The first five subsections of this section (3.2.1 to 3.2.5) follow the structure of the ‘research onion’ (Figure 3.1), whose successive layers represent the philosophies, approaches, strategies, choices, time horizons and techniques selected as appropriate to the nature of the present study (Saunders et al., 2015)

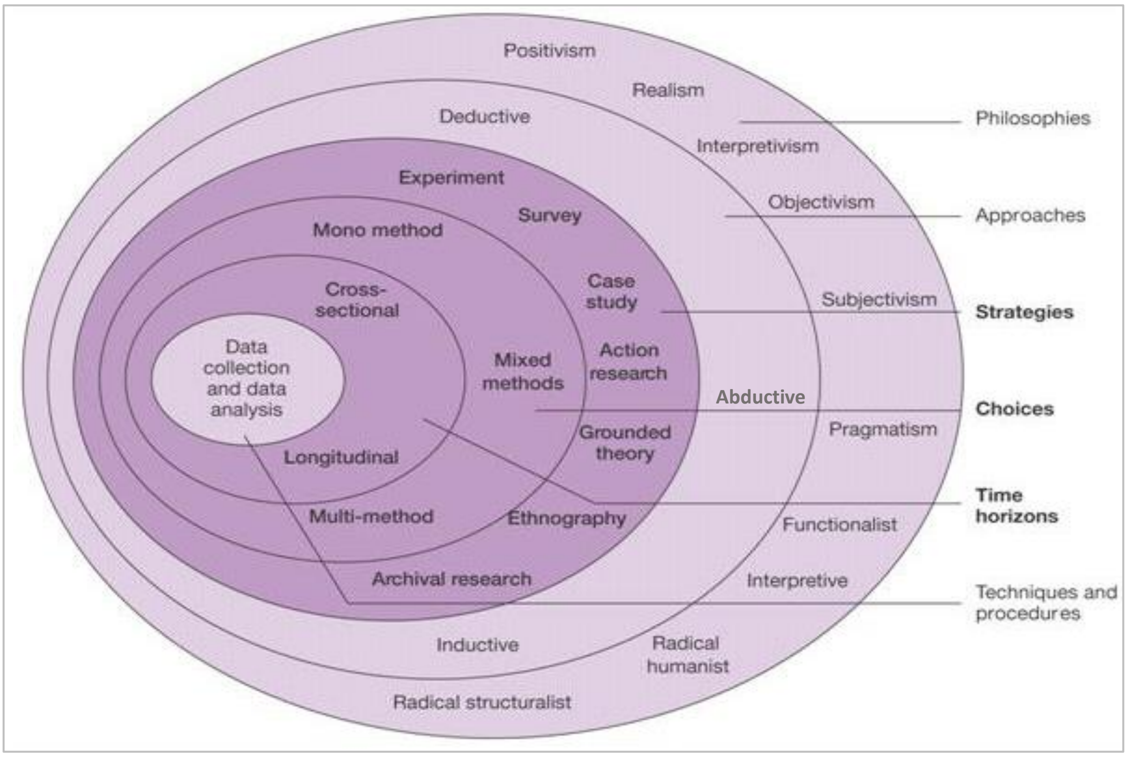


Figure 3.1: Research methodology (research onion) (Saunders et al., 2015)

3.2.1 Research philosophy

The research philosophy is the most fundamental component of any study, managing and guiding the study strategies and techniques. The research approach, which concerns the construction and logical relation of concepts, is oriented towards data collection and analysis, while the research techniques are the methods of data collection and manipulation (Sexton, 2003). Underlying these choices is the adoption of a particular philosophy, which refers to developing knowledge in a specific field to explore and develop new knowledge, consistent with the researcher's views of the nature of the world and of reality. There are three types of assumption within research philosophy: epistemology, ontology and axiology.

Epistemology concerns knowledge and how it is understood, so that researchers can accept it and communicate it to others (Sexton, 2003). The two epistemological positions considered here are positivism and interpretivism. Positivist research deals with a large sample of quantitative data and objective facts that offer rich knowledge about the matter at hand. It includes measurable features which are independent of the observation (Sexton, 2003) and can be quantified by means of objective techniques rather than being implicit or subjective feelings, opinions and reflections. Interpretivism, by contrast, focuses on explanations, narratives and accounts of human actions amongst individuals, rather than on objects, its purpose being to understand the social world (Saunders et al., 2015). Interpretive researchers assume that access to reality is essentially gained through social systems like behaviour, language and perception. They typically attempt to comprehend phenomena by the connotation of the human environment (Sexton, 2003). The present research investigates the impact of IEQ on teachers' performance. It takes a positivist stance because real measurements of IEQ were recorded and the research, by its nature, deals with physical attributes that influence teachers' performance under various indoor environmental conditions, such as IAQ, thermal comfort and lighting, which were measured to evaluate the level of performance.

Ontology concerns the understanding of the nature of reality. As with epistemology, researchers have a choice of two main stances: objectivism and subjectivism. Objectivism embraces realism. It considers social entities to be like physical objects, in a reality that is external to social actors concerned with their own thinking and existence. Subjectivism, on the other hand, embraces nominalism and integrates with the humanities. It involves the perceptions and actions of social actors (Saunders et al., 2015). Since the present research is concerned with the objective reality of the relationship between IEQ and teachers' performance, an objectivist ontological stance is more appropriate than a subjectivist one.

Axiology concerns the value of the research procedure and its importance in the natural world. It reflects the values of the researcher and the value of interactions and responses elicited during the research via questionnaires, for example, thus demonstrating either value-neutral or value-biased attitudes to the research. The positivistic axiological stance is defined by the existence of an external reality independent of individuals' opinions and of the researcher's views. The result is that the researcher disengages himself from the research environment and acts as an independent observer, without interfering in the research process (Kulatunga, 2007). This research explores the value and importance of studying IEQ to help improve the researcher's awareness.

3.2.2 Research approach

A research approach is the procedure planned to achieve the research purpose and solve the research problem. There are three types of approach: deduction, induction and abduction. A deductive approach usually starts from a general enquiry and proceeds to a specific one, starting with a theory that can be tested. It is further narrowed down into observations to address a hypothesis by testing it with accurate data. Conversely, the inductive approach starts from a specific enquiry and leads to general knowledge, utilising precise, in-depth observations and measures to identify patterns of information and to generate a hypothesis, which is developed to draw a conclusion. The abductive approach combines those two approaches, beginning with the observation of a surprising fact, then constructing a credible theory to explain the observed phenomenon. It now moves back and forth between deduction and induction, gathering new data to explore the phenomenon and to identify themes and patterns, which will have a testable conclusion (Saunders et al., 2015).

Quantitative studies are often deductive in nature, using statistical analyses to test hypotheses and so to draw conclusions concerning features of a population (Harwell, 2011; Lincoln and Guba, 1985). By contrast, qualitative research is by nature more likely to be inductive, in that the researcher can generate hypotheses, design concepts and obtain clarification from the information provided by participants (Lincoln and Guba, 1985).

This research aimed to develop a model of the effects of different IEQ factors on teacher performance. It therefore began by taking a deductive approach, then revised the research model abductively with new data.

3.2.3 Strategies

Strategy, in the context of research, means a plan of action to achieve the study's aims and objectives. Among the many strategic options available, some involve quantitative techniques, some use qualitative techniques and others rely on both (Saunders et al., 2015). Research strategies can be distinguished as based either on realist (nomothetic) or on idealist (ideographic) ontologies. Gill and Johnson (1991) explain that a nomothetic strategy employs statistical techniques of data analysis to derive truths about populations, whereas ideographic techniques are used to analyse subjective data regarding the personal life experiences of individual participants.

The most common research strategies, which differ in their use of qualitative, quantitative, or mixed methods, are narrative research, phenomenology, action research, focus groups, grounded theory, case studies, surveys and experiments (Saunders et al., 2015). The following paragraphs explain the three strategies adopted here.

An experiment is by definition a means of discovering an answer that was not known previously, relying on carefully recorded observations (Melville and Goddard, 1996). Experimental strategies are used in psychological and social studies, measuring the probability that a given change in an independent variable will cause a particular change in a dependent variable. Experimental designs include classic experiments, quasi-experiments and within-subject designs. In a classic experiment, a sample of participants is randomly assigned either to an experimental group, which undergoes the intervention to be tested, or a control group which has no intervention. A quasi-experiment can be conducted in the same way, but without randomization; instead, participants are pair matched by factors such as age, gender and length of service. A within-subject design uses a single group, so that every participant takes part in the intervention to establish a baseline (Saunders et al., 2015).

Surveys represent a popular strategy, most commonly used in deductive research. They are flexible and low in cost, since data may be collected in many different ways, such as by an email invitation to access an online database or online site link, via mobile surveys, telephone surveys, or face-to face interviews (Blumberg et al., 2008).

The case study strategy uses a real-life context to explore and develop a deep understanding of a research topic (Yin, 2003). An in-depth case study can be designed to identify what is happening and why, so that the researcher can understand causes, effects and implications. In a deductive approach, “a case study starts with a theoretical proposition to test the applicability of a research topic and to build an intensive explanation of the hypothesis” (Saunders et al., 2015). Many literature reviews mention post-occupancy evaluations (POEs) and building use studies (BUSs), which use questionnaires to evaluate the performance of a building after it has been occupied.

The present research adopts the case study strategy and takes a multi-method approach comprising experiment and survey, using quantitative methods to refine the research hypothesis and the IEQ model. Indoor physical environmental parameters were measured objectively and the results correlated with survey data, while teachers’ feedback on indoor environmental characteristics was elicited in a specific case study.

3.2.4 Time horizon

The time horizon of a research study refers to its length; cross-sectional studies are conducted within a relatively short timeframe, whereas longitudinal studies examine a series of events over a longer period, allowing comparisons between the different times (Saunders et al., 2015). The present research adopted a longitudinal studies, whereby data were collected for six months, with two months for each season to cover the entire academic year. The aim was to collect detailed IEQ data covering the annual range of climate conditions at Jeddah Technical College (JTC), which has over 400 instructors and teachers.

3.2.5 Techniques and procedures

The innermost layer of the research onion concerns the techniques and procedures of data collection and analysis. As detailed in Section 3.3, this study involved the measurement of indoor environmental variables using standard instruments, complemented with a survey to evaluate IEQ factors and teacher performance. An assessment model developed by means of the Artificial Neutral Network (ANN) function of the MATLAB platform was then used to validate the findings.

Quantitative data analysis involves both looking at the collected data graphically to represent its general trends and fitting statistical data to the model. Furthermore, as the present research involves the testing of hypotheses, statistical techniques of data analysis were considered appropriate. The ANN data were therefore divided into three phases of algorithm learning (70% of the data to train the model, 15% for validation and 15% for testing this learning), then an assessment model was developed to create new data via the proper function to test the model’s accuracy. The Statistical Package for Social Science (SPSS) software package was then used to analyse these new data, to calculate mean values, to produce results, to clarify respondents’ answers and to evaluate the newly generated data.

3.2.6 Research outline

The research was planned to unfold in four phases, illustrated in figure 3.2: 1) identification of the research problem and establishment of the aim, objectives and research questions, through a review of the relevant literature; 2) the empirical investigation, involving fieldwork and updating the model; 3) analysis and validation, culminating in the testing of the model; and 4) drawing conclusions and making recommendations. Figure 3.3 outlines the entire research process in a little more detail, in the form of a flowchart.

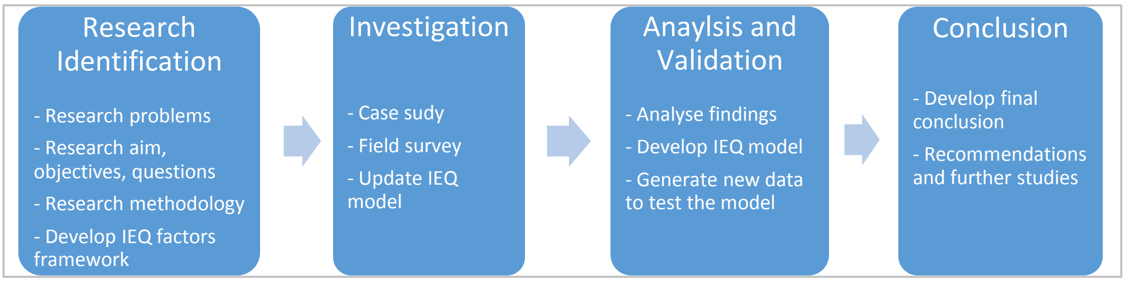


Figure 3.2: Planned research phases

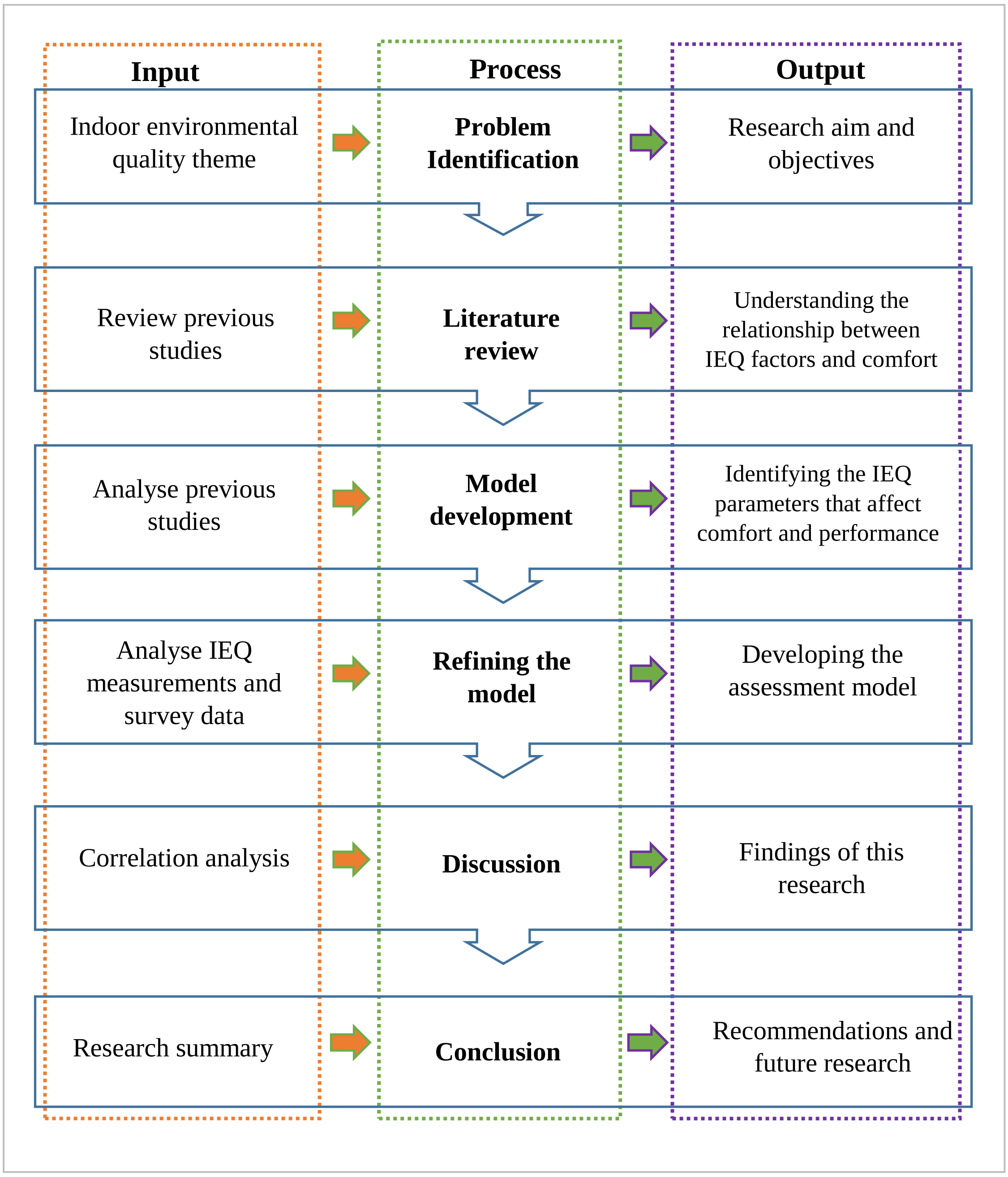


Figure 3.3: Research flowchart

The ANN flowchart is illustrated in figure 3.4 as statistical techniques that will be detailed in chapter 5.

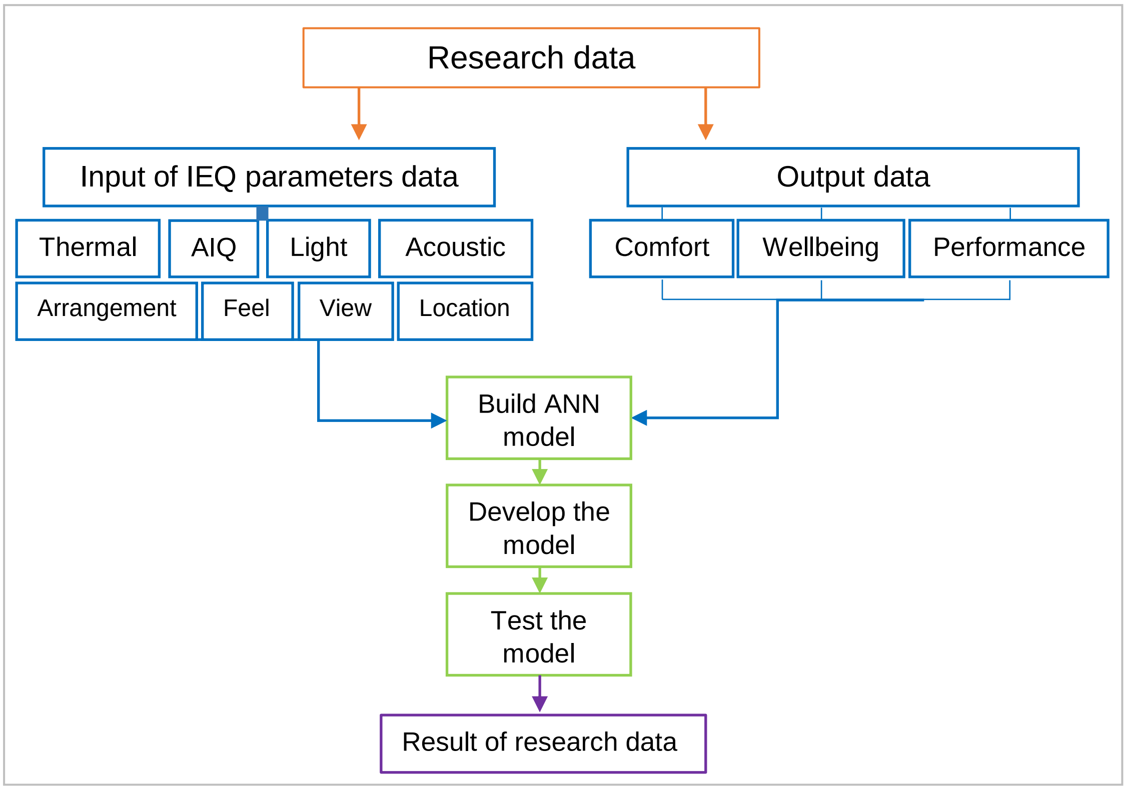


Figure 3.4: ANN flowchart

3.2.7 Reliability and validity

Reliability concerns the extent to which the methods of data gathering and analysis will generate dependable outcomes. The technique most commonly used to assess the reliability of data constructs is to measure the internal consistency between the component items or questions of an instrument (Creswell, 2003). In the current study, reliability was assessed during the survey design phase and again after the data had been collected, to assess the reliability of the responses to questionnaire items regarding IEQ conditions, as reported in Chapter 4, Section 4.4.

Validity approximates the truth level of propositions, suggestions or conclusions drawn from the data. It is related to what the results are actually concerned with. External validity can be distinguished from internal validity. The former, alternatively referred to as generalizability, concerns the level to which the outcomes are generalizable, that is, whether they can be applied equally to other circumstances or environments. Internal validity, also known as measurement validity, means the extent to which the quantitative questions actually quantify the existence of these measures. A valid questionnaire will facilitate the gathering of precise data, while a dependable one will do so consistently. In this study, the internal validity of the questionnaire refers to its ability to quantify what the study required to be quantified, meaning that the results should represent the reality of the relationships among perceptions of IEQ, performance and measurements of the indoor physical environment. As noted above, 15% of the quantitative data were used for validation.

3.3 Application of Research Methodology

This section describes the methods used to explore the relationship between IEQ parameters of academic buildings at JTC and the perceived comfort of academics, i.e. teachers, instructors and professors. The parameters in question were those of the thermal, acoustic and lighting conditions of classrooms and were recorded simultaneously with the administration of a questionnaire survey, following the practice of Cao et al. (2012). The following subsections focus in particular on how the classrooms concerned were selected, how IEQ was physically measured and how the perceptions of the teaching staff were investigated.

3.3.1 Research methods identified from the IEQ literature

A study such as this is complex, because IEQ parameters affect occupants via their appreciation of thermal comfort, IAQ, ventilation, background noise, ergonomics and lighting quality. The literature indicates that most IEQ assessments have relied on subjective surveys, while objective measurements have been overlooked. Various well established questionnaire surveys are available, but there appears to be no standardized methodology for determining sample size. Such surveys should be accompanied by the physical measurement of IEQ parameters in order to generate a rich description of the environmental conditions in a building (Heinzerling et al., 2013; Lee et al., 2012). A review of each IEQ factor separately and in relation the others is critical in order to understand the relationships between them. The literature indicates that the IEQ parameter most often explored has been thermal comfort, because of its close relationships with HVAC and energy consumption, which are major factors addressed in building design.

The research involved investigating and measuring four main aspects of IEQ: thermal comfort, indoor air quality, lighting and acoustics. There follows a detailed review of the literature on the measurement of these parameters.

3.3.2 Methods of evaluating IEQ

This section reviews the literature on the various quantitative and qualitative methods used to assess IEQ and occupant wellbeing. Recent literature reviews indicate that a few studies have investigated IEQ conditions via on-site physical measurements, occupant surveys and field observations in particular (Humphreys 2005; Lee et al., 2012; Mydlarz et al., 2013; Barrett et al., 2015; Awang et al., 2015). These three strategies may have been adopted because improving these IEQ conditions is seen to have potentially significant implications for employees' health and performance and thus for long-term business profit. The researchers conducted on-site measurements and surveys to characterize the overall environmental condition of buildings. The implementation of many strategies to evaluate the indoor physical environment is limited, however, almost certainly because of the time, effort and equipment required to make these measurements (De Dear et al., 2015; Newsham et al., 2013). Instead, most studies of IEQ have relied on occupant surveys, which are relatively easy and inexpensive to perform. Among those building types reported to have been evaluated, the second most common are institutional buildings such as schools and universities (Baker, 2011), because of the perceived value of enhancing students' and teachers' comfort, performance, health and wellbeing (Issa et al., 2011).

3.3.3 Measuring instruments

Physical indoor environmental parameters such as air temperature, relative humidity, lighting, background noise and carbon dioxide concentration are measured objectively using sensors and digital instruments. These are manufactured to recommended standards such as ASHRAE 55 (2010) and ISO 7720. The measured values of each parameter are then compared to the values recommended by standards such as EN15521 (2006) and ASHRAE (2013) to evaluate IEQ.

Nevertheless, it is often hard to find simple-to-use, low-priced, accurate sensors and instruments to conduct these measurements. Some sensors are not easy to use and need regular calibration to guarantee their accuracy (Heinzerling et al., 2013). There are also difficulties relating to the time, price and labour required to set these sensors across a building, conduct the physical measurements and then analyse the resultant mass of data (Reynolds et al., 2001). Table 3.1 lists the most important equipment reported in the literature to have been used to measure IEQ parameters.

Physical measurements are insufficient to evaluate IEQ and its effects on users' comfort and wellbeing and on building performance, in the absence of occupants' qualitative perceptions of IEQ conditions. It is thus essential to elicit users' perceptions using a POE survey; a building's occupants constitute a valuable source of rich information for its architects, designers and owners about the performance of the building from the users' perspective (Heinzerling et al., 2013).

A POE is used to assess a building's performance after occupied by a mix of quantitative and qualitative methods such as surveys, observations and performance tests. However, there is no recognised standardized process for performing a POE; several alternative processes have been validated over the years (Newsham et al., 2012). Researchers have explored occupants' self-reported comfort, health and performance using POE methods related to various IEQ parameters in educational environments (Khalil et al., 2011). Therefore, it is suitable to continue the use of POEs in the classrooms to determine the impact of IEQ on college members' comfort and teaching performance.

Table 3.1: *Equipment used to evaluate IEQ in published studies*

Equipment name (Developer)	IEQ parameters investigated				Reference
	Thermal comfort	IAQ	Lighting	Acoustics	
SCATs instrumented cart (CBE Berkeley)	Air temperature; globe temperature; air speed; RH. Instruments tethered to cart and placed on occupants' desktops	CO_2	Illuminance	Sound pressure level	Nicol and Cartney (2001)
Instrumented chair-like cart (CBE Berkeley)	Air temperature, air velocity and globe temperature at 0.1, 0.6, 1.1 m; dew-point temperature and chair surface temperature at 0.6 m; RA	NA	Illuminance	NA	Heinzerling et al. (2013)
IEQ cart (Faculty of Architecture, Uni of MB and EH Price, Winnipeg)	Air temperature; air speed; RH	CO_2, CO, PM tot	Illuminance	Sound pressure	Chiang et al. (2002) Mallory-Hill and Westland (2012)
NRC indoor climate evaluator (NRC)	Air temperature, globe temperature, RH, air speed	CO_2, HCHO CO, VOCs, PM(0.3-1 mm)	Illuminance, camera for HDR	Sound pressure	Newsham et al. (2012)
IEQ logger (CBE Berkeley)	Air temperature, globe temperature, radiant temperature	CO_2	Horizontal and vertical illuminance	Sound pressure	Wong et al. (2008)
Enviro Bot (CBE Berkeley)	Air temperature at 0.1, 0.6, 1.1 m; RH; hand-held air speed and radiant temperature	CO_2, CO, PM tot, TVOC	Illuminance	NA	Choi et al. (2013)
Comprehensive IEQ monitoring cart (CBE Berkeley)	Air temperature and globe temperature at 0.1, 0.6, 1.1, 1.7 m; air speed; RH	CO_2, CO, PM tot, TVOCs	Illuminance	Sound pressure	Kim and Haberl (2012)
Pyramid desktop device (NRC)	Air temperature; air speed; RH	CO_2	Illuminance	Sound pressure	Newsham et al. (2012)

The method most commonly used to compliment quantitative measurements is the survey, which is often the lowest-cost and simplest way of assessing IEQ (ASHRAE, 2012). In addition, a survey delivers information about users' perceptions of IEQ, which can differ from the physical IEQ conditions of a building, providing valuable data for building owners and operators (Muhič and Butala, 2004).

Several survey tools have been industrialised to study occupants' perceptions of buildings' IEQ. Peretti and Schiavon (2011) and Mallory-Hill and Westland (2012) conducted intensive reviews of such tools, including Cost-effective Open-Plan Environments (COPE) (Veitch et al., 2007), the Occupant Survey, Building Assessment Survey and Evaluation Study (US EPA, 2003), Building Use Studies (BUS), the Health Optimization Protocol for Energy (HOPE) Efficient Buildings Project (Bluyssen et al., 2011) and the Centre for the Built Environment (CBE) Survey (Baker, 2011). The existence of such a range of tools reflects the lack of a standard method of surveying building occupants. Nonetheless, a review of the literature indicates that the two most widely used tools are the CBE and BUS surveys. The latter has been used in a range of settings, specifically in residential and office buildings, while the CBE survey is reported to be the most widely used survey tool, gathering data from more than 60,000 respondents globally, in over 600 buildings, mostly offices (Peretti and Schiavon, 2011).

3.3.4 Comprehensive IEQ benchmark studies

The studies reviewed above examined the IEQ components of thermal, acoustic and lighting conditions, whereas those considered in this subsection take a more holistic approach to determining the relationships among the multiple factors of IEQ and teachers' comfort or performance.

Lee et al. (2012) measured physical IEQ factors and the corresponding satisfaction levels of students and academic staff at The Hong Kong Polytechnic University. They took IEQ readings during lectures delivered by professors in eight teaching rooms: four have 60-seat and four 140-seat in lecture halls. The purpose of this cross-sectional study was to create a database of occupant IEQ satisfaction levels, classroom characteristics and IEQ readings, to help to predict the level professorial satisfaction.

A 27-item questionnaire was used to collect teacher and student satisfaction levels from 312 participants using the binary code for acceptance (0 = unacceptable, 1 = acceptable) of four factors: thermal, IAQ, lighting and noise. Manual readings and features of the rooms were recorded, including size, shape, room type, panel height, air supply, high noise area, location of windows and lighting types. The researchers used instrument combining several sensors to measure one or more IEQ aspects, with which they recorded sound level, temperature, air movement, air quality and illuminance. These readings were taken once in each room over a thirty-minute period. The study used the following recommended levels:

- Temperature: 24.5-28 °C (ASHRAE, 2004)
- Relative humidity: 30% (Smedje and Norback 2000; ASHRAE, 2004).
- Carbon dioxide concentration: ≤ 1000 ppm (EN15521, 2006).
- Noise level: 45 dBA ±3 (Veitch et al., 2007; Bradley and Gover, 2004; Newsham et al., 2012)
- Desktop illuminance: 300-500 lux (IESNA, 2000).

The regression coefficients constructed from the field measurements, the acceptance had statistical significance with thermal comfort and IAQ, as did the overall IEQ. In contrast of acceptance of thermal comfort and IAQ, teachers could adjust the lighting in order to achieve (90%) of occupants would find visual quality acceptable for different tasks. Windows were the most desirable attribute of teaching rooms, although teachers close a window were unsatisfied with the acoustic and privacy factors of the built environment. The researchers suggest that this maybe related to the proximity of the window, which reflects lacks privacy and sound from the outside. Teachers and students within the temperature between (23.5 and 21.5 °C) were more comfortable, as were teachers within the recommended illuminance range (300 to 500 lux).

Mydlarz et al. (2013) collected data in a pilot study of 12 school buildings in England, selected to explore the performance levels of school. The 203 classrooms evaluated based on age, design form and physical indoor environmental factors such as light intensity, relative humidity, temperature and CO_2 concentration. The researchers also recorded ventilation modes, room dimensions and student numbers. All of the measurements were taken at a specific position in the classrooms to minimize interruption to teaching. The measuring instruments were all located on a table in front of the researcher, 0.7 m from the floor. Twelve schools were measured during 20 months from November 2009 to June 2011. Each measurement was taken for between five and ten minutes. Some of the recommended measurement standards that were used to benchmarking the study's findings were:

- Temperature: 20 to 23.5 ºC for winter and 23 to 26º C for the summer months (ASHRAE 55, 2010, 2013)
- Relative humidity: 30-60% (BB 101, 2006; Ajiboye et al., 2006; ASHRAE 55, 2010)
- CO_2 concentration ≤1000 ppm (EN ISO 7730, 2005; EN15521, 2006)
- Sound level: 35-50 dBA (EPA Victoria, 1999; BB 93, 2006; ANSI/ASA, 2010)
- Illuminance: 300-500 lux (BB90, 1999; EPA Victoria, 1999; IESNA, 2000)

The results show that average perception of thermal comfort were mostly in the standard values for all schools; however, measurements of one school were recorded in the warmer months with natural ventilation. Lighting measurements showed that a third of classrooms fell below the minimum level of 300 lux, with 60% dropping below 500 lux, the recommended minimum level for complicated tasks. A remarkably high glare factor was recorded in one of the school, due the orientation of classrooms relative to the sun. Poor IAQ readings were notified in two schools, while CO_2 level had the most variation between schools, but only 39% of all recorded classrooms exceeded the maximum CO_2 level of 1000 ppm. As to acoustic quality, classroom sound levels ranged from 45.5 to 79.6 dBA, with only 20% of all schools meeting the acoustic standard.

Fadeyi et al. (2014) investigated IEQ in school classrooms in the United Arab Emirates (UAE). In this study, public and private of sixteen elementary schools were conducted to collect data in two emirates, Dubai and Fujairah, between April 2012 and February 2013. Dubai schools were selected to address typical urban schools, while those in villages in Fujairah were taken as typical of schools in rural areas of the UAE. The objective was to compare conditions in UAE classrooms with recommended IEQ standards. Electronic instruments were used to collect physical data on thermal conditions, i.e. temperature and relative humidity (RH), CO2 concentration, sound level and light level. This study, which provides useful data on environmental conditions in UAE classrooms, used the following recommended levels as benchmark standards:

- 23 to 26º C (73.4 to 78.8º F) for summer months (ASHRAE 55, 2010; 2013; Dubai Municipality, 2010; ISO 7730, 2010)
- 30-60% relative humidity (BB 101, 2006; ASHRAE 55, 2010; Dubai Municipality, 2010)
- ≤1000 ppm of CO_2 (EN ISO 7730, 2005; EN15521, 2006; Dubai Municipality, 2010; ASHRAE 62.1, 2013).
- 35-50 dBA (EPA, 1999; BB 93,2006; ANSI/ASA, 2010; Dubai Municipality, 2010)
- 300-500 lux (BB90, 1999; EPA, 1999; IESNA, 2000).

The results of this study show that the average CO_2 concentration in the classrooms ranged between 786 and 4050 ppm. The majority of the rooms had concentrations above recommended levels, due to poor ventilation, with substandard flow rates. As to thermal conditions, average temperature in the 16 classrooms ranged between 20.5 and 27.7 °C. One classroom was cooler than the recommended range, while five were warmer. Relative humidity levels were all within recommended values, ranging from 31% to 52%. An average sound level of 59 dB was recorded for all classrooms, making them noisier than the applicable standard. Major indoor sources of noise causing poor acoustic quality were air-conditioning systems, mechanical fans and unavoidable classroom activities. Average light levels ranged between 138 lux and 742 lux.

Six classrooms had averages in the range of 400-700 lux, ten averaged above the recommended minimum of 300 lux and of the six which fell below this minimum, two were very poorly lit, in the range of 100-200 lux.

The above studies examined IEQ factors (thermal, acoustic and lighting conditions) as they relate to comfort and IEQ measurements. Their findings indicate that components of IEQ can greatly affect classroom comfort as perceived by teachers' perceptions of IEQ components. Notably, none of the researchers related their findings to school design strategies or environmentally constructed buildings.

This research provides information about the IEQ of conventional educational buildings and measurement methods, while indicating the advantages of using a multiple-method approach to obtain a consistent assessment of teacher comfort, performance and IEQ in educational buildings.

3.4 Development of Methods

The present study investigates the relationship between IEQ and teacher performance through the development of a model which assumes that when teachers are more comfortable with aspects of their classrooms, which have a high quality of physical environmental parameters, this will affect their performance positively. The predictor variables were constructed of physical measurements taken from the classrooms in five academic buildings at JTC, where the academic day ran from 8:00 am to 2:45 pm, five days per week. Lectures lasted about two hours in general, while a few lasted three hours. Some classrooms were used for only one or two lectures per day, similar to teaching rooms in universities.

The registration system of the college was accessed to identify 42 classrooms, each of which was fully occupied on a given day in each academic term, when IEQ was evaluated and recorded three times, making a total of 126 times in the autumn term. This method was repeated for 44 classrooms in the winter term and 38 classrooms in the spring term, making a total of 372 records over the whole year. The physical indoor environmental variables were constructed from a questionnaire survey completed by teachers in each of the classrooms. There were three periods during which IEQ parameters were measured inside the classrooms and a total of 124 teachers participated by completing the questionnaire in each term.

The study can be considered quasi-experimental, because a convenience sample was selected for practicality and because of the predicted significance of the findings concerning the association between teacher performance and physical aspects of indoor environmental quality. The following subsections deal successively with the three methodological components of the field research: on-site physical measurements, the teacher survey and field observations.

3.4.1 On-site physical measurements

This research measured IEQ parameters by means of digital instruments combining several sensors, each designed to measure one or more IEQ parameters. Their specifications met the ASHRAE 55, ISO 7730 and IEC 61672 standards and they were calibrated according to the manufacturer’s instructions prior to all measurements. Table 3.2 shows that the measurement of IEQ aspects and performance criteria focused on evaluating the indoor physical parameters of temperature, relative humidity, ventilation rate, illuminance, CO_2 concentration and sound pressure. The review of the literature identified the specific variables to be measured for each IEQ factor and the specific sensor to be used to measure each factor, as shown in Table 3.2. It also identified the specific strategies to be used to measure each aspect and the recommended values or ranges of values for each parameter.

Table 3.2: *IEQ measurement equipment*

IEQ aspect	Parameters	Instruments	Recom-mended	Mounting Height	References
Thermal Comfort	Air temperature	1-4 Environment device Temp/RH/Light Level	23 to 26 ºC	0.60 m	ASHRAE 55 2010; 2013; Dubai Municipality, 2010; ISO 7730, 2005;
	Relative humidity		30-60%	1.0 m	BB 101, 2006; Ajiboye et al., 2006; ASHRAE 55, 2010; Dubai Municipality, 2010;
	Air velocity		0.1 to 0.2 m/s	1.0 m	ASHRAE 55 2010; 2013; EN15521, 2007
IAQ	Carbon dioxide concentration	Telaire 7001 CO_2 Sensor	≤1000 ppm	0.80 m	EN ISO 7730, 2005; EN15521, 2007; Dubai Municipality, 2010; ASHRAE 62.1, 2013
Lighting quality	Illuminance	Minolta T-10A Illuminance Meter	300-500 lux	0.80 m	BB90, 1999; EPA 2003; IESNA, 2000
Acoustic quality	Sound pressure level	Larson Davis 831 Sound Level Meter	35-50 dBA	0.80 m	EPA, 1999; BB 93, 2006; ANSI/ASA, 2002; Dubai Municipality, 2010

The Saudi building code includes no data or standards on IEQ, so the researcher used the Municipal Code of Dubai, which has a similar climate other characteristics, and international standards as benchmarks to assess IEQ. These values were found in several standards such as ASHRAE (2010, 2013), the Acoustical Society of America (ANSI/ASA, 2002) and ISO 7730, 2010). The method involved defining the units for each parameter, the mounting heights of the sensors and the measurement periods. Because of the limited of standards and forms of guidance for educational buildings in general, many of standards and methods applied as part of this methodology were related to office building standards.

Choi et al. (2013) suggest that specific standards should be developed for schools in the future, but these are not expected to be much different from those for office buildings, except that the sensor height would need to be adjusted in accordance with students' seating level. Air temperature and air velocity were recorded in accordance with the ASHRAE 55 (2004) standard for thermal comfort and the heights of the sensors used to measure these factors were adjusted to the recommended standard height of 0.80 m. CO_2 concentration, ventilation rate and odour have often been used as IAQ indicators (Kamaruzzaman et al., 2015). ASHRAE 62.1 (2013) recommends, "CO_2

concentrations indoors do not exceed outdoor concentrations by average of 700 ppm”. Outdoor levels were recorded between 450 and 500 ppm, whereas the maximum indoor limit is around 1,100 ppm. Light quality was measured horizontally according to the IESNA (2000) standard, which specifies an acceptable range of intensity of 300-500 lux. ANSI/ASA (2002) recommends an acoustic pressure level of 35-50 dB for an effective teaching and learning environment.

3.4.2 Teacher survey and performance

The study surveyed teachers on their perceptions of comfort with their classrooms and took physical readings of the actual thermal, acoustic and lighting conditions in these workspaces. The advantages associated with survey design are the low cost of questionnaires, the rapidity of data collection and the ability to capture perceptions of several variables at once. Additionally, the data captured are usually suitable for statistical analysis of probabilities (Nardi, 2005). The advantage of collecting physical readings is that they provide a description of the actual indoor environment. The readings can then be benchmarked against established standards and teachers’ perceptions.

The occupant survey, to evaluate teachers’ comfort with the IEQ of their classrooms and its effects on wellbeing and performance, was conducted after having received human ethics approval from the University of Salford Education Research Ethics Board (Appendix I). The questionnaire, taking a subjective approach, was based on the EN ISO 10551(2001) standard, the POE questionnaire model, the CBE model and other studies (Abbaszadeh et al., 2006; Fowler and Rauch, 2008; Lee and Guerin, 2009; Choi et al., 2013). It had three main sections, covering different criteria (Appendix II reproduces the complete questionnaire).

The questionnaire elicited classroom information included building code, location, lectures time and academic terms. Forty-seven items were related to teacher comfort with the IEQ components of IAQ, thermal, lighting and acoustic conditions. They were rated by the teachers on a five-point Likert scale (1= “Strongly disagree” to 5 = “Strongly agree”). The first section comprised nine multiple choice items on participant demography in general, related to age, educational qualification, hours worked per week, years of service and room occupancy (Table 3.3).

Table 3.3: *Constructs, questionnaire items and measures of occupant demographics*

Variable category	Theoretical construct	Questionnaire item	Measure
Demographics	Human organism	Age	≤30, 31-40, 41-50, ≥51
		Length of service at JTC	≤1, 1-2, 3-5, ≥5 years
		Highest educational qualification	Bachelor's, master's, doctorate
	Social environment	Hours worked per week	≤10, 11-15, 16-20, ≥21 hours
		Student number in class	≤15, 16-20, 21-25, ≥26
		Lectures period	8-10/10-12/1-3 o'clock
		Academic term	Autumn-Winter-Spring
	Design environment	Building code	C-D-E-F-G
		Room number and floor	Floors 0,1,2; rooms 01-15 (005 means ground floor, room 5)

The second section, on indoor environmental conditions, was in five parts. The first, on comfort with the physical characteristics of the room, comprised five items about layout and arrangement, classroom size, student numbers, colours and textures, furniture and equipment. The second part, on thermal conditions, comprised one multiple choice item on thermal sensation and five Likert scale items on temperature, humidity, air movement, natural and mechanical ventilation, accessibility of a thermostat and overall acceptability of thermal comfort. The third part contained four items about indoor air quality: air movement, cleaning of air, odour and level of IAQ acceptance. The fourth part, on lighting quality, contained one multiple choice item on light control methods and five Likert scale items on daylight level, artificial light quality, visual condition, ability to control lighting level and overall acceptability of lighting. The final part, on sound quality, contained five Likert scale items about sources of noise and the overall acceptability of acoustic quality. The second section of the questionnaire is summarized in Table 3.4, along with the third section, on the impact of IEQ factors on performance and wellbeing, rated on a five-point Likert scale (1= "very negatively " to 5 = "very positively ").

The teachers' survey was administered while IEQ measurements were being recorded. Teachers were invited to take the survey by divisional superintendents. Each received an email invitation to participate, with a consent letter, as mandated by the University of Salford Research Ethics Board. Divisional superintendents handed the questionnaire survey to them in a lecture period at the same time as the measurements were taken.

Table 3.4: *Constructs, questionnaire items and measurement of classroom characteristics*

Variable category	Theoretical construct	Questionnaire item	Measure
Physical conditions	Design environment	Layout and arrangement	Likert-type scale: Strongly disagree (1) to Strongly agree (5)
		Classroom size	
		Comfort with number in class	
		Colours and texture	
		Furniture and equipment	
Thermal conditions	Design environment	Temperature	Likert-type scale: Strongly disagree (1) to Strongly agree (5)
		Humidity	
		Mechanical ventilation	
		Accessibility to thermostat	
		Overall acceptability of thermal comfort	
		Thermal sensation	Hot, warm, slightly warm, neutral, slightly cool, cool, cold
IAQ	Design environment	Air condition: stuffy/stale	Likert-type scale: Strongly disagree (1) to Strongly agree (5)
		Air not clean	
		Air smells bad	
		Overall acceptability of IAQ	
Lighting conditions	Designed/ natural environment	Acceptability of daylight quality	Likert-type scale: Strongly disagree (1) to Strongly agree (5)
		Adequate artificial light	
		Comfort of visual condition (glare, reflection)	
		Ability to control amount of light	
		Overall acceptability of light quality	
		Method of light control	Window blind/shade, light switch, light dimmer, no control
Acoustic conditions	Design environment	Noise from heating, ventilation and cooling system	Likert-type scale: Strongly disagree (1) to Strongly agree (5)
		Noise from other classrooms	
		Noise from corridor	
		Noise from outdoors	
		Overall acceptability of IAQ	
Influences of IEQ	Human perception	IEQ affects performance (8 items)	Likert-type scale: Very negatively (1) to Very positively (5)
		IEQ affects health and wellbeing (8 items)	

They received email reminders at the end of the first week and one day before the scheduled survey, as recommended by the CBE survey (Baker, 2011).
The researcher ensured the confidentiality and security of survey responses. To maintain teacher anonymity, a unique code was assigned to each classroom, comprising a letter (C-G) for the building, followed by three digits denoting the floor and room number; for example, C210 means room 10 on the second floor of building C. Given the anonymity of survey responses, the research team could identify neither the teachers who had participated in the survey nor their email addresses.

The invitations were emailed to the departmental chairman, who forwarded them to participants, but did not receive any of the survey responses and could not identify any of the teachers who had participated. The paper-based data were stored in a locked cabin and will be destroyed completely two years after completion of the research. None of the data will be passed on to anyone. They will all continue to be stored securely and only the researcher will have access to them.

As the focus of the study is on indoor environmental quality and its impact on teacher performance, the survey did not address aspects of teaching, learning and administration outside the control of building designers. Nor was it concerned with financial considerations that might influence the quality and maintenance of the buildings, or with health issues such as respiratory illnesses or absenteeism which have been associated with IEQ and building features. The survey, while subjective, was tailored precisely to its purpose, which was to elicit teachers' perceptions of their comfort with a number of IEQ variables and their effect on their teaching performance.

3.4.3 Field observations

Observation was used to record other data not included in the survey or in the IEQ measurements, such as site location, outside weather conditions on measurement days, the teaching equipment available in classrooms (e.g. projectors, computers and printers), floor and wall colours and finishes, classroom layouts and sizes. These data were intended to supplement the physical measurements and survey responses with evidence of aspects of IEQ such as look and feel, view, location and amenities. Photographs were also taken on the measurement days to illustrate these features visually.

3.5 Method Implementation

The case study was of academic buildings on the campus of Jeddah Technical College, located on the west coast of the red sea at 21°42' N latitude and 39°10'E longitude. The city of Jeddah, lying 70 km west of Mecca, has a population of about 4.4 million and is located in a region of Saudi Arabia where the hot season covers most of the year, so air conditioning is in constant operation. The measurements of physical indoor environmental parameters were made during autumn, winter and spring. The autumn readings were taken in September 2016, when the average temperature in Jeddah was 35 °C, the maximum was 40 °C and the minimum was 28 °C. At the time of the winter readings, in January 2017, the respective figures were 27 °C, 31°C and 24 °C, while in April 2017, when the spring readings were made, they were 32 °C, 36 °C and 26 °C respectively (Figure 3.5).

The average relative humidity values in the same three months were 61%, 62% and 47% respectively. Visibility was ten miles and cloud conditions were reported as mostly sunny to overcast with a maximum of 16% in January (Figure 3.6).

There was some variation in wind speed during the period of fieldwork. The north westerly wind reached a maximum speed of 19.7 mph and average gust speed of 15.9 mph in September, while the respective speeds in January were 15.4 mph and 13.2 mph, and in April 19.5 mph and 16.6 mph.

An outdoor five -minute reading of acoustic conditions was taken prior to each set of morning, noon and afternoon readings and again after the last afternoon reading. The mean values were: morning, 60.71 dBA; noon, 54.10 dBA; afternoon, 61.6 dBA; and end of day, 57.1 dBA. The overall mean of the outdoor readings was 58.37 dBA. In spring, a large central shading device was constructed in the central area of the site, approximately 12 metres from four of the academic buildings. On the days of the readings, the construction work involved much hammering on wood and metal, but ceased during midday prayers and lunch, which explains the lower mean dBA values at noon.

The case study was limited to the classrooms in the five academic buildings of JTC, which is an academic facility of the Training and Vocational Technical Corporation. JTC was established in 1985 as one of the largest technical colleges in Saudi Arabia, with approximately 7,000 students and 450 employees. The academic year is divided into two semesters of 18 weeks each. Students must accrue 82 credit hours over four semesters to graduate with a diploma and two further years to earn a bachelor degree.

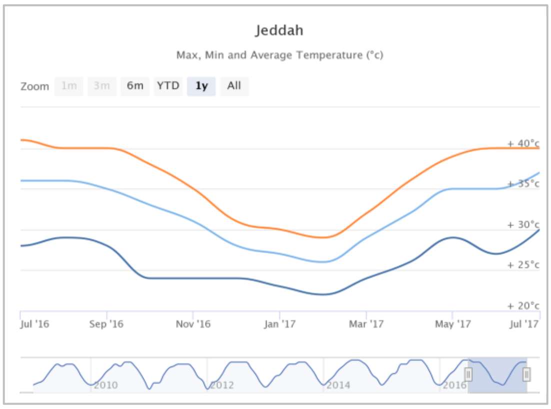


Figure 3.5: Max, min and average temperature in Jeddah

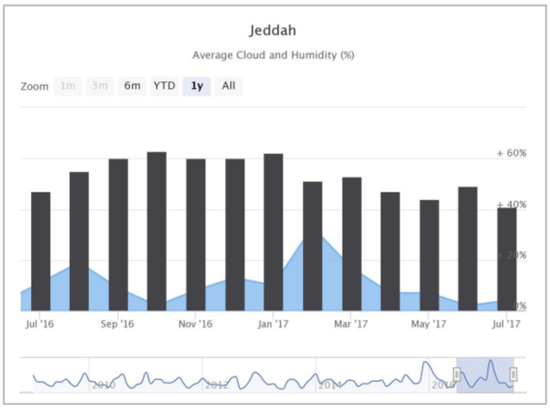


Figure 3.6: Average relative humidity and cloud in Jeddah

Source: https://www.worldweatheronline.com/jeddah-weather-averages/makkah/sa.aspx

In 2013, JTC moved to its current 250 000 m^2 campus (Figure 3.7), which apart from the five teaching buildings, contains one administrative building, one main event hall, an activity centre, a central restaurant and an operations and maintenance building, none of which was studied because they were beyond the scope of the research. The five academic buildings were all built to a single design, with overall dimensions of 32.65 x 63.5 m and three floors. The ground floor of each block contained four workshops and laboratories, three classrooms and an amphitheatre.

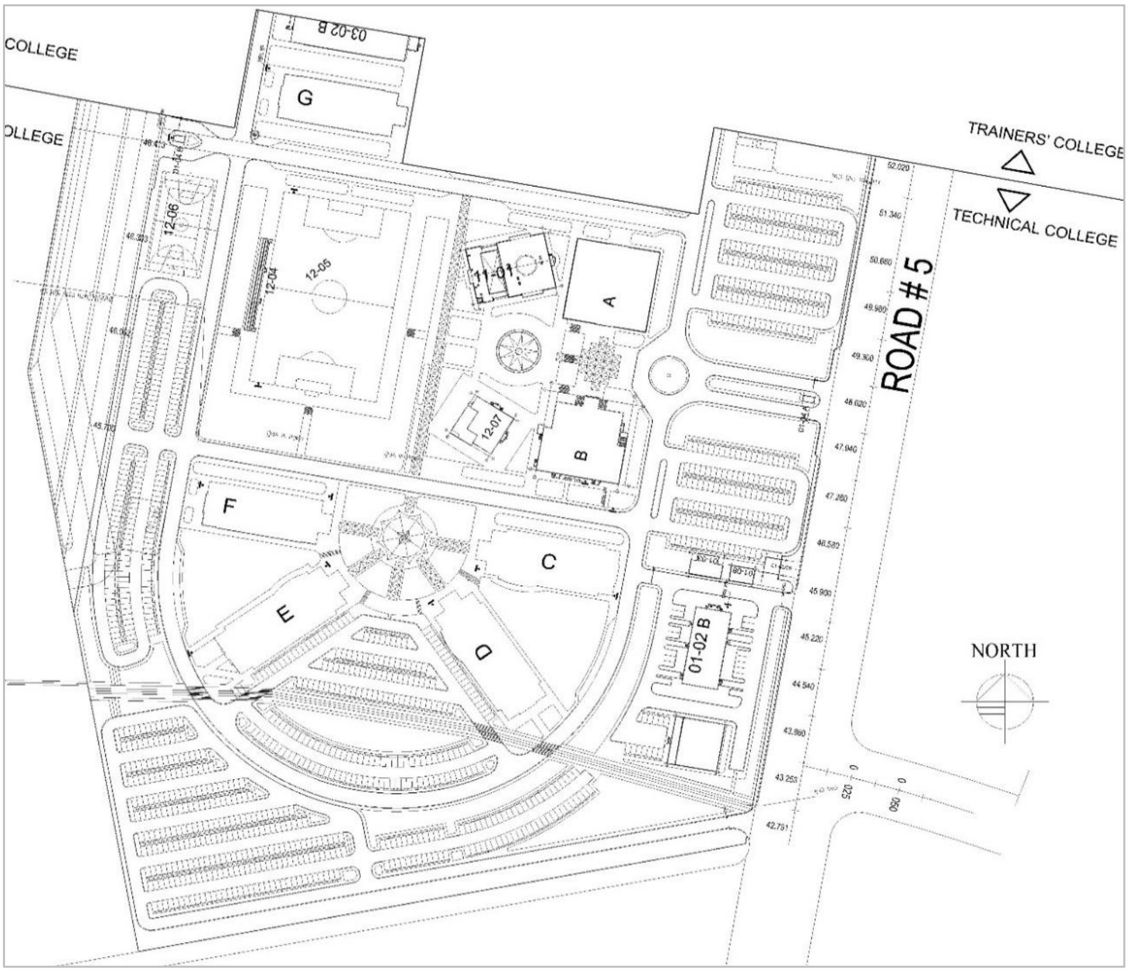


Figure 3.7: Site plan of the JTC campus in Jeddah

The first floor contained eleven classrooms, some of which were used for drawing courses, and the second floor contained five computer labs, three classrooms, teachers' offices, a meeting room and an open-plan lobby used for relaxation and prayer. The basic architectural plan featured a 3.4 m wide corridor along the length of the building with classrooms on either side. The ground floor and first floor classrooms had an average width of 6.90 m and length of 9.90 m, making an area of 68.3 m^2, while those on the second were 6.90 m x 11.10 m (76.5 m^2). Each building was allocated to a separate college department, so at the construction phase some departments had some pairs of rooms combined into double rooms to allow room for experimental equipment for practical classes. Figure 3.8 (a, b, c) shows the basic plans of the buildings, which were constructed of precast concrete with exteriors finished in beige with dark red stripes.

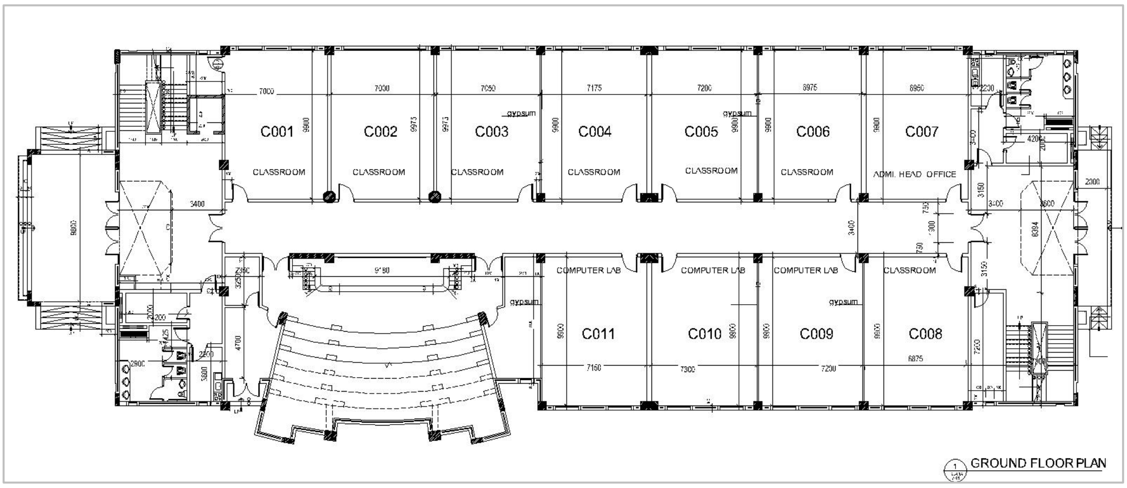


Figure 3.8a: Ground floor plan of academic buildings

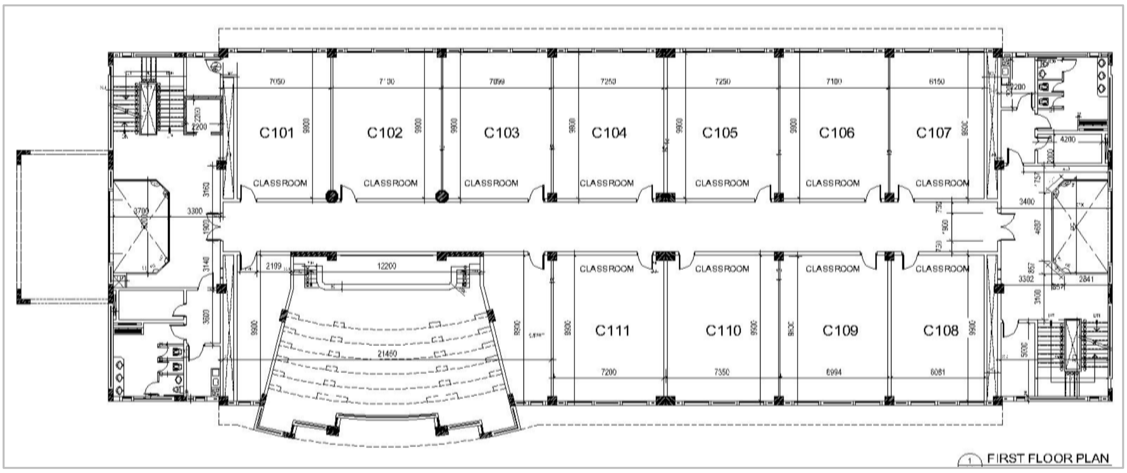


Figure 3.8b: First floor plan of academic buildings

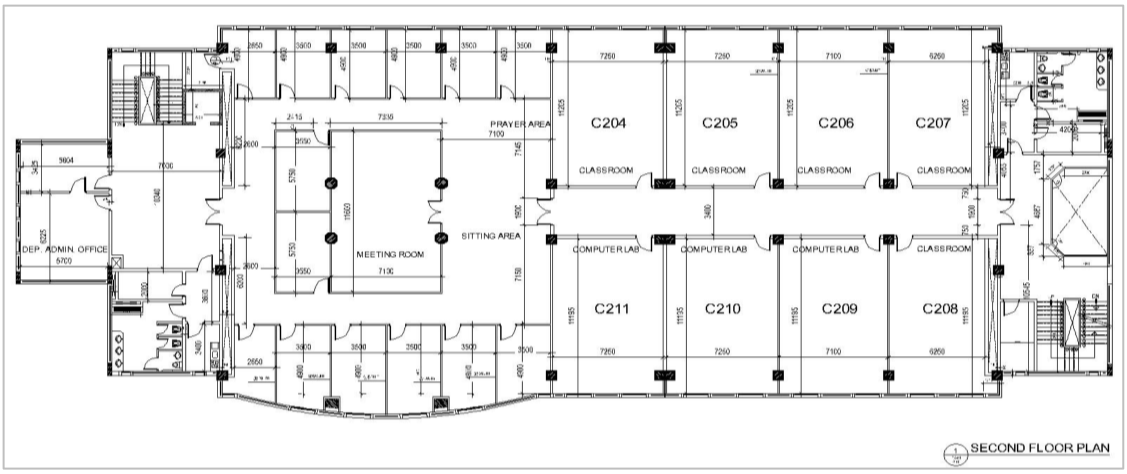


Figure 3.8c: Second floor plan of academic buildings

The classroom floors were finished with square tiles 45 x 45 cm in beige and light brown. Some walls were constructed of concrete blocks finished in cream (Figure 3.9), while other demising walls were of gypsum board partitions on metal frames. These were not full height from floor to slab, which may have allowed noise to enter classrooms from computer labs and other classrooms.

Each classroom had two windows of double glazing in framed panels with roller blinds. The glazed area of each room was 4.5 m^2, representing about 25% of the total area of the right and left walls, as shown in Figure 3.10. The HVAC system of each building consisted of 12 packaged systems located on the top floor. Each cooling unit comprised an expansion valve, evaporator, air handling blower and filter, hanging from the ceiling. Ducts of 0.60 m x 0.60 m connected each classroom to a cooling unit. Armstrong ceiling tiles were used, containing six 0.60 m x 0.60 m air conditioning diffusers on a grid. Lighting fixtures were compact fluorescent lamps, also 0.60 m x 0.60 m on the ceiling grid (Figure 3.11 (a, b)).

The rooms were furnished with rows of portable chairs, each with a desk fitted for learning tasks, facing the teacher's table at the front of the room with a computer and printer. Adjacent to the teacher's desk, a projector was fixed to the front wall near the ceiling (Figure 3.12 (a, b)).

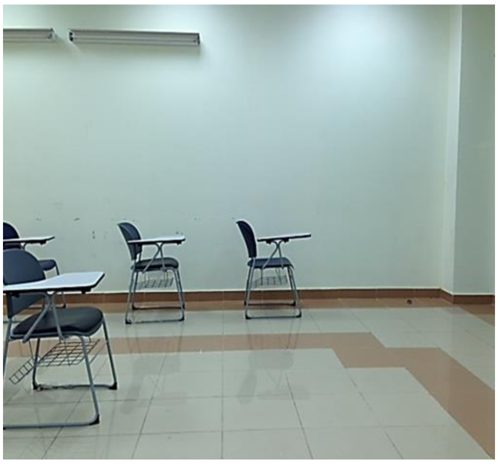


Figure 3.9: Wall and floor colours

Figure 3.10: Windows in classrooms

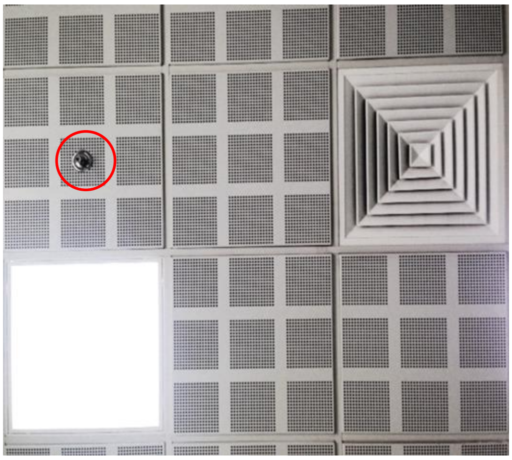


Figure 3.11a: Lighting, air conditioning diffuser and alarm system

Figure 3.11b: Ceiling tile grid with lighting

Figure 3.12a: Classroom arrangement

Figure 3.12b: Teaching equipment

3.6 Indoor Environmental Quality Measurement

The physical IEQ measurements were made in September 2016, January 2017 and April 2017. This assessment included a visual inspection of classrooms and the physical evaluation of the different IEQ parameters measured using electronic instruments. Prior to visiting each building, the researcher sent an email to all classroom teachers to confirm the dates and times of the scheduled visits. The procedures followed during every visit are outlined below:

- Once on site, the researcher notified the teachers and students in every classroom involved of the time of the physical IEQ measurements.

- The IEQ parameters were recorded at three places (front, centre and back) in each classroom then the average was calculated, following the procedure used by Awang et al. (2015). Readings were taken in the presence of students and teachers, interrupting classroom activities as little as possible, to capture the actual classroom environment.

- Questionnaires were handed to teachers and observations of each classroom's finishing, furniture and layout were captured with photographs at the same time.

Readings of IEQ elements (IAQ, thermal, acoustic and lighting conditions) were taken at designated locations throughout the five academic buildings. All instruments were calibrated according to the manufacturers' instructions. Readings were taken in selected classrooms on all three floors. The temperature was measured using a 1-4 Environment device, which was placed as recommended 0.60 m above the floor surface, clear of any sources of heat (PC monitors, motors, or other electronics). Air velocity and relative humidity were measured in each selected classroom, approximately 1.0 m from the floor as recommended by ASHREAE-2010 Standard 55 data and by Dubai Municipality (2010). CO_2 was measured as an indicator of IAQ using a Telaire 7001 CO_2 Sensor at a height of 0.80 m in line with EN15521 (2007) and Dubai Municipality (2010). Decibel readings were taken at desktop height (0.80 m), as recommended by ANSI/ASA (2002) and Dubai Municipality (2010), for an average of five minutes, using a Larson Davis 831 device. The five-minute acoustic standard was used in previous studies (Navai and Veitch, 2003; Tang and Wong, 1998). Finally, a Minolta T-10A was used to take single illuminance lux measurements at a height of 0.80 m, adopting the methodology used by Moore et al. (2002).

In order to capture diurnal changes in IEQ parameters, thermal, IAQ, acoustic and lighting values were measured three times in each selected classroom over the course of one day: between 8:15 am and 9:45 am, from 10:15 am to 11:45 am and between 1:15 pm and 2:45 pm. Appendix V lists all classroom schedules.

The schedule of readings was created randomly after the classrooms had been selected, to determine which readings would be taken in the five buildings in the morning, the middle of the day and the afternoon and to ensure that the same characteristics of the classrooms (orientation, location and capacity) were measured on the same day. The teaching schedule was considered when determining the reading schedule.

In some places where measurements were taken, noise created by student traffic in the corridor, teachers' voices and classroom activities, especially when doors were opened, may have influenced the noise readings, because not all of the demising walls were full height, as noted above. Additionally, there was a smell of tobacco smoke in the classrooms near the toilets and on the ground floor. Each selected classroom had one reading scheduled during each season, although one teacher may have had the quality of his indoor environment evaluated twice. Table 3.5 shows the schedule of readings.

Table 3.5: *Sample of measurement schedule*

Class rooms	8:00 am	Morning reading schedule						10:00 am	Mid-day reading schedule						12:00 am	Afternoon reading schedule						3:00 am
		8:15-9:45							10:15-11:45							1:15-2:45						
D210	Outdoor reading		×					Outdoor reading	×						Outdoor reading	×						Outdoor reading
D103		×									×						×					
C104				×						×									×			
C103						×							×					×				
E001							×							×							×	
G009					×							×								×		

An X in the table indicates a reading that was taken 15 minutes after the start of the class. The full measurement schedule is reproduced in Appendix III.

In summary, according to Saunders et al. (2015), research methodology refers to the principles and processes of logical thought and the procedures used to produce theory, including the research philosophy, approach and strategies.

Since there are many alternative ways to design a research study, the research onion was used as a guide in constructing the general plan of this study.

The research approach means the procedures adopted to achieve the objectives of the research and to fulfil its aim. There are three forms of approach: deduction, induction and abduction. The deductive approach usually starts from a general enquiry and leads to a specific one, whereas the inductive approach starts from a specific enquiry and proceeds to general knowledge. The abductive approach combines the two approaches, starting with the observation of a surprising fact, leading to the construction of a specific theory to explain the observed phenomenon. It then moves back and forth between deduction and induction. The deductive approach was taken in the present study to collect appropriate data and build the assessment model, which was then revised abductively with new data.

In this study, 372 measurements for each of indoor environmental variables were recorded over a whole academic year using standard instruments, complemented with a survey to evaluate IEQ factors and teachers' performance. The sensors and digital instruments were manufactured to recommended standards such as ASHRAE 55 (2010). The measured values were compared to the recommendations of standards such as EN15521 (2006) and those of the Dubai Municipality (2010) to evaluate the various IEQ factors. The occupant survey, to evaluate teachers' comfort with the IEQ of their classrooms and its effects on wellbeing and performance, was based on global standards such as the POE questionnaire model, the CBE model and other studies. Forty seven items were related to teacher comfort with the IEQ components on a five-point Likert scale (1= “Strongly disagree” to 5 = “Strongly agree”).

The artificial neutral network function of the MATLAB platform was implemented as a statistical technique of data analysis in order to build an assessment model, which was then developed to validate the findings. The ANN data were therefore divided into three phases of algorithm learning (70% of the data to train the model, 15% for validation and 15% for testing this learning), then the developed model was used to create new data in order to test its efficiency.

3.7 Conclusion

This chapter has presented full details of the methodology adopted in the present research, beginning by explaining and justifying the philosophical and practical choices made as to how the aim and objectives would be addressed, using as a guide the ‘research onion’ model. Philosophically, this study of the relationship between the physical indoor environment and teacher performance takes an objectivist ontological stance and makes positivist assumptions on the epistemological dimension.

A multiple-method approach was chosen, whereby a case study with experiment and survey techniques was used to collect the data. This entailed physical measurements of indoor environmental parameters in classrooms and a quantitative questionnaire survey of teachers’ perceptions of comfort and the effects of IEQ factors on their performance, in order to develop an assessment model.

The survey sample was selected by a non-probability technique. The questionnaire items were closed-ended and divided into three sections, on participants’ demography, their acceptance of IEQ factors and the effects of IEQ on their wellbeing and performance. Objective measurements of IEQ parameter were made repeatedly in each classroom in accordance with a fixed schedule, while respondents completed the survey and the researcher made contemporaneous observations.

This chapter has also explained the study’s full ethical compliance. The following chapter reports the analysis of the data collected from the survey, observations and measurements, detailing data entry and cleaning, measurement data analysis and survey data analysis. The descriptive nominal data are presented in the form of pie charts, while the ranked ordinal data are represented by frequency distributions.

Chapter 4

Analysis of Physical Environment Measurements and Survey Data

Data analysis is an essential process that helps to achieve the study objectives and therefore to accomplish the research aim. This chapter presents an analysis of the data collected by physical measurements, observation and questionnaire survey, as reported in the previous chapter. This involved preparing the data, entering them into a computer and checking their quality, then selecting the most appropriate graphic representations to explore them further.

4.1 Introduction

Experimental designs generally compare one or more measures of the physical indoor environment to an interactive outcome. These environmental attributes are related to users' physiological sensory domains and include the visual, thermal and respiratory environments (Mendell and Heath, 2005). Chapter 3 has described the methods used to collect data objectively by measurement and subjectively via a survey to explore the association between physical indoor environmental variables and teacher performance. As reported there, the physical measurements were taken during the administration of the survey in order to check the validity of the questionnaire responses. These measured data were used to determine the physical environmental conditions prevailing in each classroom, using recommended instruments as explained in Chapter 3.

The indoor environment, including the distribution of heat and ventilation by the mechanical HVAC system, varies in both space and time across classrooms and buildings. The measurements of indoor environmental parameters were compared with the relevant global standards, such as ASHRAE 55 (2013), to investigate the performance of the building and to determine its efficiency in terms of each parameter. Because Saudi building codes do not incorporate standards for measures of IEQ, the benchmark standards used here to evaluate these parameters were those adopted by the Dubai Municipality (2010), whose code is based on international metrics such as the ASHRAE Standard 62.1-2007, the Building Bulletin 101, the ASHRAE Standard 55-2010, the IESNA lighting handbook and BB90 (1999). These standards set values of indoor physical parameters relative to comfort, namely temperatures of 23 to 26 °C, relative humidity of 30-60%, CO_2 concentration of ≤1000 ppm, background sound level of 35-50 dBA and illuminance of 300-500 lux.

The subjective data were elicited by means of a questionnaire based on the POE questionnaire model and other published sources such as Lee and Guerin (2009), in order to evaluate teachers' perceptions of IEQ conditions and to investigate their effect on the participants' comfort, wellbeing and performance.

The reliability of the subjective survey data was assessed by measuring the degree of covariation of the study variables.

4.2 Analysis of Indoor Physical Environment Measurements

Saunders et al. (2015, p. 187) define the case study as a deductive approach that "starts with a theoretical proposition to test the applicability of a research theme and to build an intensive explanation of the hypotheses''. The case study strategy can be used to explore a real-life phenomenon in order to obtain a deep understanding of a research topic and to develop a model or framework to fulfil the study's aim and objectives (Yin, 2003).

As explained in Chapter 3, the present case study was conducted in five basically similar three-storey academic buildings of the Jeddah Technical College, on the Red Sea coast, in a region of Saudi Arabia where air conditioning systems are in use throughout the year.

The methods used to measure the environmental parameters were explained in Chapter 3. These measurements were taken in a total of 124 selected classrooms, fully occupied during all academic semesters, making a total of 372 records. Some of these classrooms were measured two or three times during different seasons, while others were not, depending on their occupancy. Figure 4.1 shows a plan view of the first floor of building D and a chart of the measurements taken in each of the selected classrooms indicating the average values of parameters recorded over three seasons. All measurements—of temperature, relative humidity, CO_2 concentration, light level and sound level—were taken while the HVAC system was running. The top line of each portion of the chart indicates the range of recommended international standard values for comparison.

The highest mean temperature recorded in these classrooms was 26.90 °C, in room D103 in the 10:15-11:45 slot, while lowest was 22.20 °C, in the same time slot in room D104. Both of these values lie outside the range recommended in the ASHRAE standard and the Dubai Municipality code. However, 80% of the temperature records for building D were within the recommended standard range.

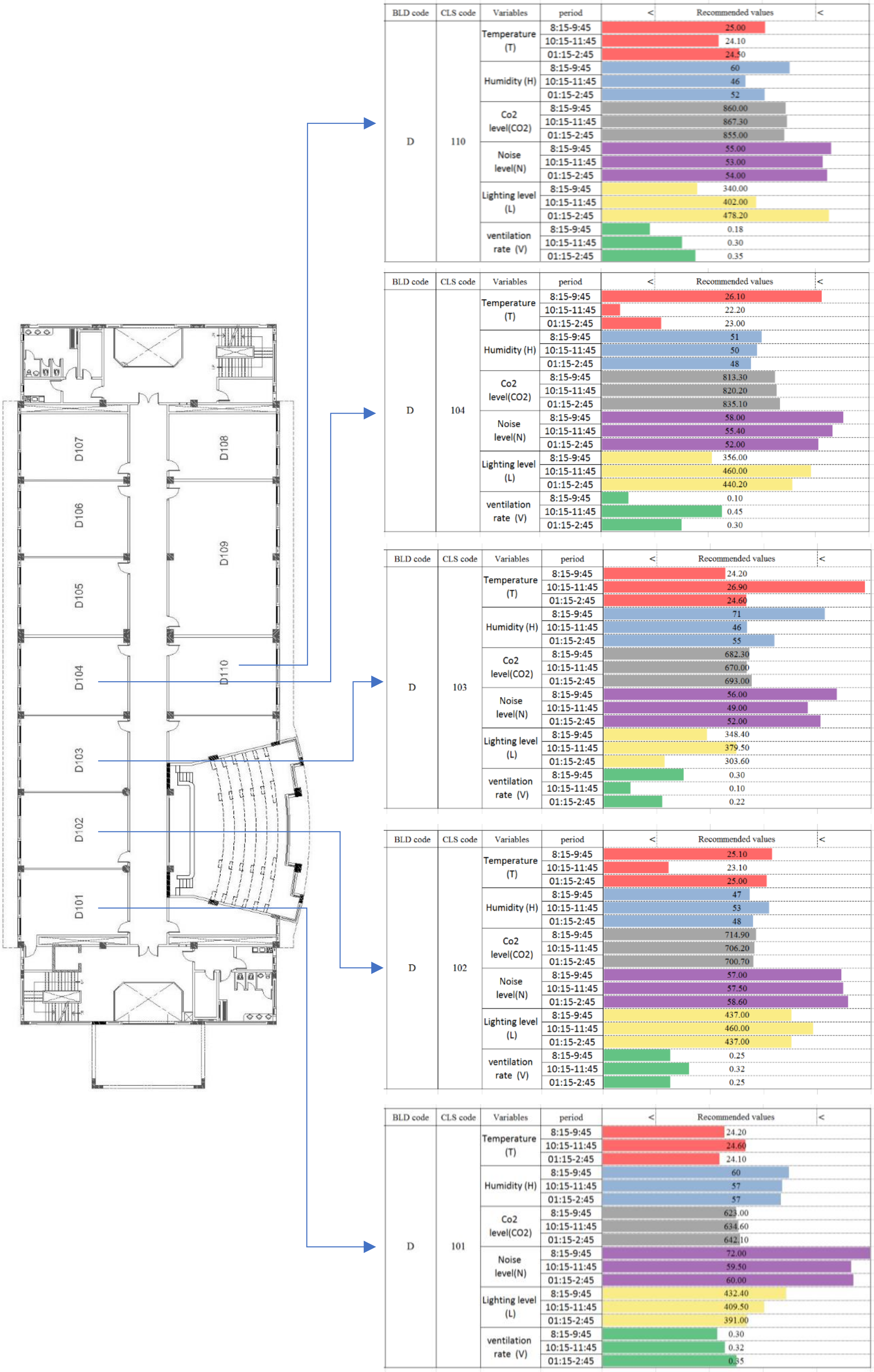
The relative humidity measurements ranged from 46% in D110 at 10:15-11:45 to 71% in D103 at 08:15-11:45. The latter value slightly exceeded the recommended maximum, but 93% of relative humidity records in building D were within the standard range.

Average CO_2 concentration varied from 623 ppm in room D101 at 08:15-09:45 to 867 ppm in D110 at 10:15-11:45. Overall, 82% of CO_2 readings in building D were within the recommended range.

The background sound level ranged between 49 dBA in D103 at 10:15-11:45 and 72 dBA in D101 at 08:15-09:45. In marked contrast to the other parameters, only 34% of decibel readings taken in this building matched the standard.

Finally, measured light levels lay between 303 lux in D103 at 01:15-02:45 and 478 lux in D104 at 10:15-11:45. In building D, 100% of all light measurements taken were within the standard range. All measurements taken in all classrooms are tabulated in Appendix IV.

Analysis of the environmental measurements made in all of the classrooms indicates relatively good overall compliance with standards, as 84% of temperature records, 92% of relative humidity, 87% of CO_2, 88% of light levels and 42% of sound readings fell within the recommended ranges. Thus, the indoor environment was of good quality in terms of four physical parameters, the only concern being that the background sound level tended to be excessive, indicating a noisy environment.



BLD code	CLS code	Variables	period	Recommended values
D	110	Temperature (T)	8:15-9:45	25.00
			10:15-11:45	24.10
			01:15-2:45	24.50
		Humidity (H)	8:15-9:45	60
			10:15-11:45	46
			01:15-2:45	52
		Co2 level(CO2)	8:15-9:45	860.00
			10:15-11:45	867.30
			01:15-2:45	855.00
		Noise level(N)	8:15-9:45	55.00
			10:15-11:45	53.00
			01:15-2:45	54.00
		Lighting level (L)	8:15-9:45	340.00
			10:15-11:45	402.00
			01:15-2:45	478.20
		ventilation rate (V)	8:15-9:45	0.18
			10:15-11:45	0.30
			01:15-2:45	0.35

BLD code	CLS code	Variables	period	Recommended values
D	104	Temperature (T)	8:15-9:45	26.10
			10:15-11:45	22.20
			01:15-2:45	23.00
		Humidity (H)	8:15-9:45	51
			10:15-11:45	50
			01:15-2:45	48
		Co2 level(CO2)	8:15-9:45	813.30
			10:15-11:45	820.20
			01:15-2:45	835.10
		Noise level(N)	8:15-9:45	58.00
			10:15-11:45	55.40
			01:15-2:45	52.00
		Lighting level (L)	8:15-9:45	356.00
			10:15-11:45	460.00
			01:15-2:45	440.20
		ventilation rate (V)	8:15-9:45	0.10
			10:15-11:45	0.45
			01:15-2:45	0.30

BLD code	CLS code	Variables	period	Recommended values
D	103	Temperature (T)	8:15-9:45	24.20
			10:15-11:45	26.90
			01:15-2:45	24.60
		Humidity (H)	8:15-9:45	71
			10:15-11:45	46
			01:15-2:45	55
		Co2 level(CO2)	8:15-9:45	682.30
			10:15-11:45	670.00
			01:15-2:45	693.00
		Noise level(N)	8:15-9:45	56.00
			10:15-11:45	49.00
			01:15-2:45	52.00
		Lighting level (L)	8:15-9:45	348.40
			10:15-11:45	379.50
			01:15-2:45	303.60
		ventilation rate (V)	8:15-9:45	0.30
			10:15-11:45	0.10
			01:15-2:45	0.22

BLD code	CLS code	Variables	period	Recommended values
D	102	Temperature (T)	8:15-9:45	25.10
			10:15-11:45	23.10
			01:15-2:45	25.00
		Humidity (H)	8:15-9:45	47
			10:15-11:45	53
			01:15-2:45	48
		Co2 level(CO2)	8:15-9:45	714.90
			10:15-11:45	706.20
			01:15-2:45	700.70
		Noise level(N)	8:15-9:45	57.00
			10:15-11:45	57.50
			01:15-2:45	58.60
		Lighting level (L)	8:15-9:45	437.00
			10:15-11:45	460.00
			01:15-2:45	437.00
		ventilation rate (V)	8:15-9:45	0.25
			10:15-11:45	0.32
			01:15-2:45	0.25

BLD code	CLS code	Variables	period	Recommended values
D	101	Temperature (T)	8:15-9:45	24.20
			10:15-11:45	24.60
			01:15-2:45	24.10
		Humidity (H)	8:15-9:45	60
			10:15-11:45	57
			01:15-2:45	57
		Co2 level(CO2)	8:15-9:45	623.00
			10:15-11:45	634.60
			01:15-2:45	642.10
		Noise level(N)	8:15-9:45	72.00
			10:15-11:45	59.50
			01:15-2:45	60.00
		Lighting level (L)	8:15-9:45	432.40
			10:15-11:45	409.50
			01:15-2:45	391.00
		ventilation rate (V)	8:15-9:45	0.30
			10:15-11:45	0.32
			01:15-2:45	0.35

Figure 4.1: Physical indoor environmental parameters recorded in building D

4.3 Descriptive Analysis of Survey Data

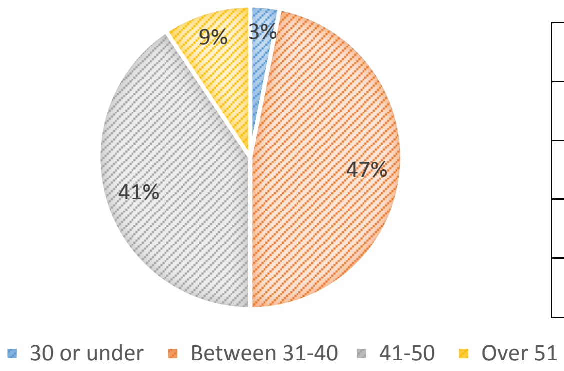
The target population of the study comprised the teachers in all occupied classrooms in all five academic buildings on the JTC campus. The sample was accessible teachers, part-time and full-time, teaching classes on all three floors of these buildings, excluding those in laboratories and computer labs. The first section of the questionnaire comprised items about the participants' demography. The second section, about the physical indoor environmental properties of the classrooms, was in two parts, the first about participants' perceptions of comfort with these IEQ parameters and the second about the effects of IEQ on their wellbeing and performance.

4.3.1 Demography of participants

The approximate sample size of 372 teachers was adequate to conduct a reliable statistical analysis. The respondents provided valuable fundamental data and it is recommended that future studies using a multi-method strategy should continue to collect both survey data and physical readings, but should target a larger number of respondents.

4.3.1.1 Participant's ages

Of the potential sample of 372 academic staff members (teachers), a total of 321 gave valid responses to the questionnaire, equivalent to an approximate response rate of 83%. The remainder were excluded for reasons of consistency as explained below. Figure 4.2 details the age breakdown, showing that almost half of respondents were aged between 41 and 50 years and that most of the rest were aged 31 to 40.

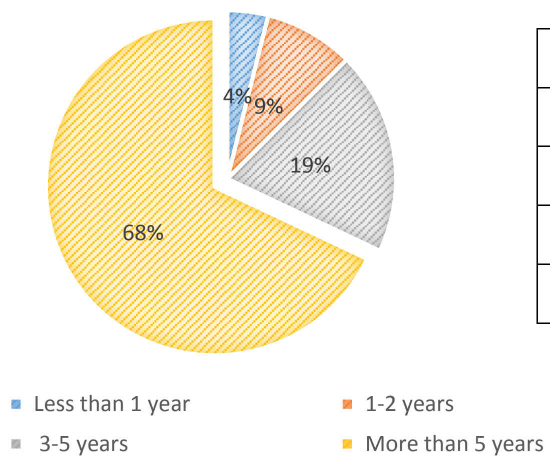


Participant's ages in years		
30 or under	11	3%
31-40	150	47%
41-50	131	41%
51 or over	29	9%

Figure 4.2: Participants' age groups

4.3.1.2 Length of service at JTC

Participants were asked how many years they had worked at the college. Sixty-eight percent had more than five years' service, indicating familiarity with the conditions in the classrooms and other parts of the buildings, which would help them to assess the quality of the indoor environment accurately. As Figure 4.3 shows, a further 19% had served at least three years and only 4% of respondents had taught at JTC for less than a year.

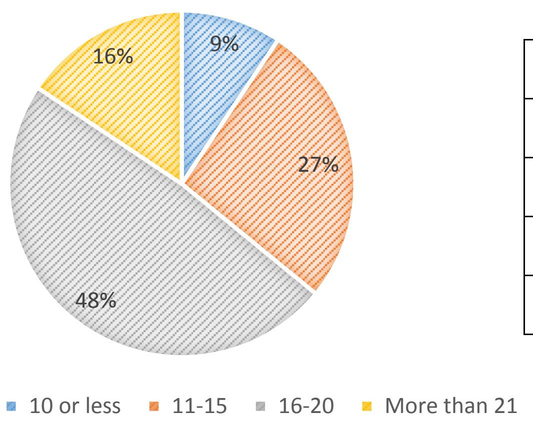


Length of service at JTC		
Less than 1 year	13	4%
1-2 years	27	9%
3-5 years	63	20%
More than 5 years	218	68%

Figure 4.3: Length of service at JTC

4.3.1.3 Hours per week at college

Teachers were normally required to work 24 hours per week at the college, but not all of this time would be spent in the classroom, since many had other duties, as student advisers or counsellors, administrative assistants, collection representatives, directors, managers or supervisors. As to their teaching duties, Figure 4.4 shows that approximately three quarters of respondents were in the classroom for between eleven and twenty hours per week, while only nine percent, who had other positions in the college, taught for ten hours per week or less.

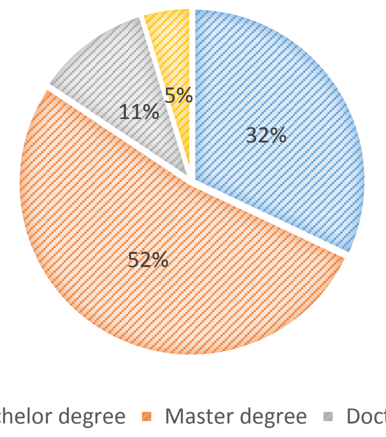


Teaching hours per week		
10 or less	31	9%
11-15	77	27%
16-20	139	48%
More than 21	51	16%

Figure 4.4: Teaching hours per week

4.3.1.4 Highest educational qualification

Participants were asked to state their highest educational qualification. As Figure 4.5 shows, a third had a bachelor's degree, half had a master's degree and 11% had a doctorate, leaving only 5% with lesser qualifications such as diplomas or high school certificates.

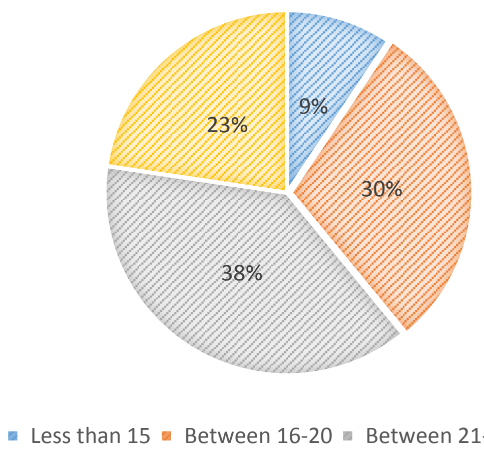


Highest educational qualification		
Bachelor’s degree	103	32%
Master’s degree	168	52%
Doctorate	34	11%
Others	16	5%

Figure 4.5: Participants’ highest educational qualification

4.3.1.5 Number of students in classrooms

While the indoor environmental parameters were being measured, the researcher counted the number of students in each classroom. It can be seen from Figure 4.6 that two thirds of rooms had between 16 and 25 students present, while around a quarter were more densely occupied than this and only 9% had fewer than 15 students.



Number of students in classrooms		
Fewer than 15	30	9%
16-20	95	30%
21-25	123	38%
More than 26	73	23%

Figure 4.6: Student numbers in classrooms

4.4 Reliability Assessment

Before turning to the analysis of the subjective questionnaire data on indoor environmental factors and their effects on teachers' comfort, wellbeing and performance, it was important to evaluate the internal consistency of the measures to establish whether they were sufficiently reliable (Boyle et al., 1995; Klassen and Chiu, 2011). Since the IEQ variables were measured on multi-item scales, Johnson et al. (2007) suggest the use of Cronbach's alpha, which is the most widely used coefficient for assessing the internal consistency of measures of IEQ. It measures the degree of covariation that exists among the study variables, in the range of zero to one. A low alpha value indicates that the items have not reliably captured the concept, while a high value indicates that the given items correlate well with the true scores. The alpha value, therefore, sets the lower limit of a scale's reliability and in most conditions it provides a conservative estimate of this (Carmines and Zeller, 1979). Cortina (1993) and Kline (1999) suggest that an acceptable value for Cronbach's alpha would be around 0.7 and above, while values significantly lower than 0.7 indicate unreliable data. Table 4.1 shows that an alpha coefficient value of 0.5 or less is considered unacceptable, while 0.9 or above is excellent.

Table 4.1: *Acceptable values for reliability* (Takavol, 2011; Dunn et al., 2013)

Cronbach's alpha value	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

The responses to the 42 questionnaire items on the indoor environmental parameters affecting teachers' degree of comfort, wellbeing and performance were analysed using the SPSS software, revealing 76.5% of internal consistency between them. In other words, the Cronbach's alpha value was 0.765, which is considered acceptable but not good. In order to improve the level of reliability, the responses of relatively inexperienced teachers (those with three years' service or less who were mostly under 30 years old) were excluded from the data, leaving 321 valid responses. The reliability assessment was then repeated and consistency between the answers was found to have increased to 87.2%, equivalent to an alpha value of 0.872, which is considered to reflect a good level of reliability of the construct.

4.5 Indoor Environmental Quality of Classrooms

The second section of the questionnaire survey was in two parts, the first containing items assessing the extent of respondents' agreement with statements regarding the effect on their comfort of aspects of the physical indoor environment. In the second part, teachers were asked to assess the strength of the positive or negative effect of each IEQ factor on their wellbeing and performance.

4.5.1 Comfort with non-instrumental factors

The assessment of teachers' comfort began with five items on classroom IEQ factors that were not measured instrumentally. They were asked to state their strength of agreement or disagreement with statements on the comfort of the furniture and equipment, colours and textures, classroom size, student numbers and layout. Figure 4.7 shows that on balance, teachers tended to agree that the furniture and equipment were comfortable, with 39% agreeing more or less strongly and 28% disagreeing, but a third expressed neutrality and fewer than a third expressed strong opinions. On colours and textures, more than half of participants either agreed or strongly agreed, a quarter were neutral and only 18% disagreed. Almost half of respondents were comfortable with the number of students in the classrooms, the remainder being equally divided between those who disagreed and those who were unsure. Consistently with these responses, almost 60% of teachers agreed that the rooms were comfortable in terms of size. Again, about a quarter of responses were neutral. The largest single score in this part of the survey was the 53% who agreed that the layout of the rooms was comfortable. A further 5% strongly agreed and once more almost a quarter were undecided, leaving 18% of negative responses.

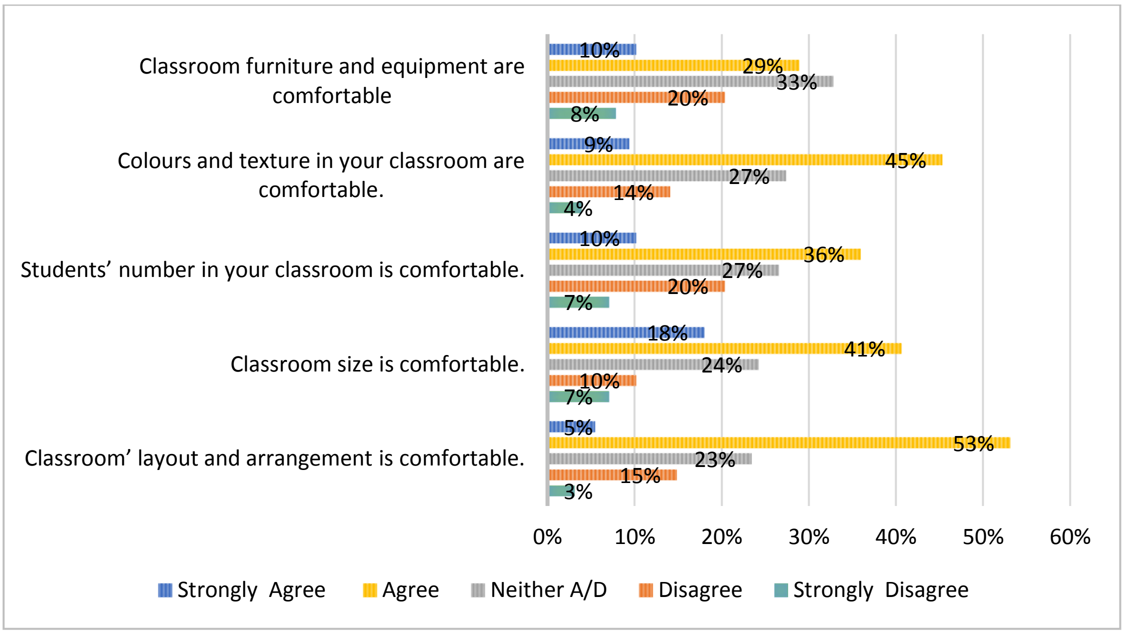


Figure 4.7: Comfort with non-instrumental factors

4.5.2 Thermal comfort

The questions on instrumentally measured parameters began with five items on thermal comfort. Figure 4.8 lists the statements with which respondents were asked to agree or disagree and the percentage of the sample who gave each response. The strongest agreement was the 51% who agreed that classroom temperature was suitable in addition to 10% who agreed strongly, whereas only 19% expressed any level of disagreement with this statement. On the suitability of the humidity level, more than half agreed or strongly agreed, 42% were unsure and only 5% recorded any level of disagreement. More than half of responses on mechanical ventilation were also positive and a third were neutral. As to overall thermal comfort, above 60% of teachers found this acceptable and only 12% disagreed. There was one item, however, to which the responses were predominantly negative: almost three quarters of teachers were dissatisfied with the accessibility of the thermostat.

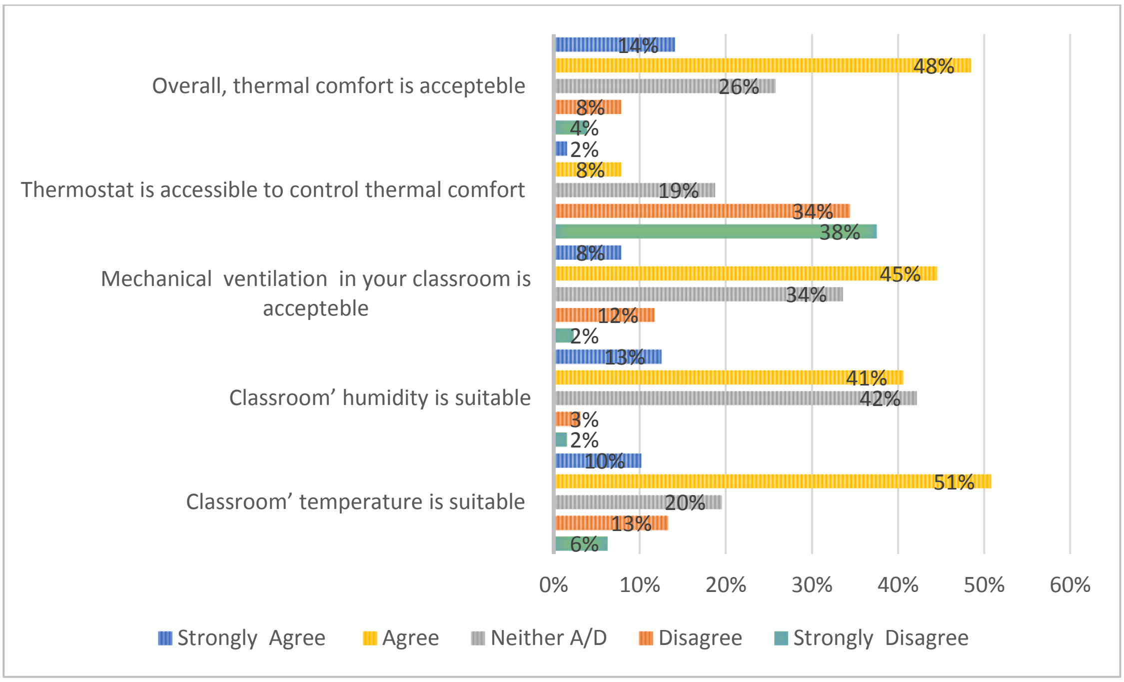


Figure 4.8: Thermal comfort survey of classrooms

Participants were next asked to select an adjective to describe their thermal sensation in the classroom. Figure 4.9 shows that extreme responses were rare: among the seven options, the central three (slightly cool, neutral and slightly warm) accounted for 88% of answers, with very few teachers considering the room to feel cold, cool, warm or hot.

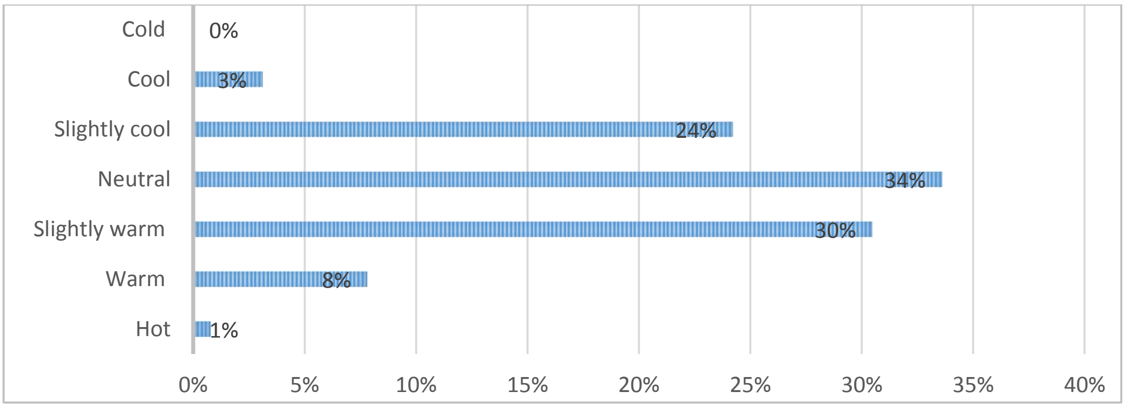


Figure 4.9: Thermal sensation of participants

4.5.3 Indoor Air Quality

There were four items on indoor air quality, indicating the freshness of the air and its freedom from biological or chemical contaminants. Figure 4.10 reveals that 37% of teachers were unsure whether the air was stuffy or stale and that the remaining responses were roughly equally divided between positive and negative assessments of stuffiness, with slightly more (35%) considering it not to be stuffy. Similarly, a small majority gave favourable responses to an item on the cleanliness of the air, with a third saying it was not clean and a quarter being undecided. The most favourable set of responses concerned odour, as only 19% agreed or strongly agreed that the air smelled bad, while more than half of the sample disagreed with this assertion. Consistently with these individual assessments, 59% of teachers agreed that IAQ was acceptable overall, 22% were neutral and only 20% disagreed.

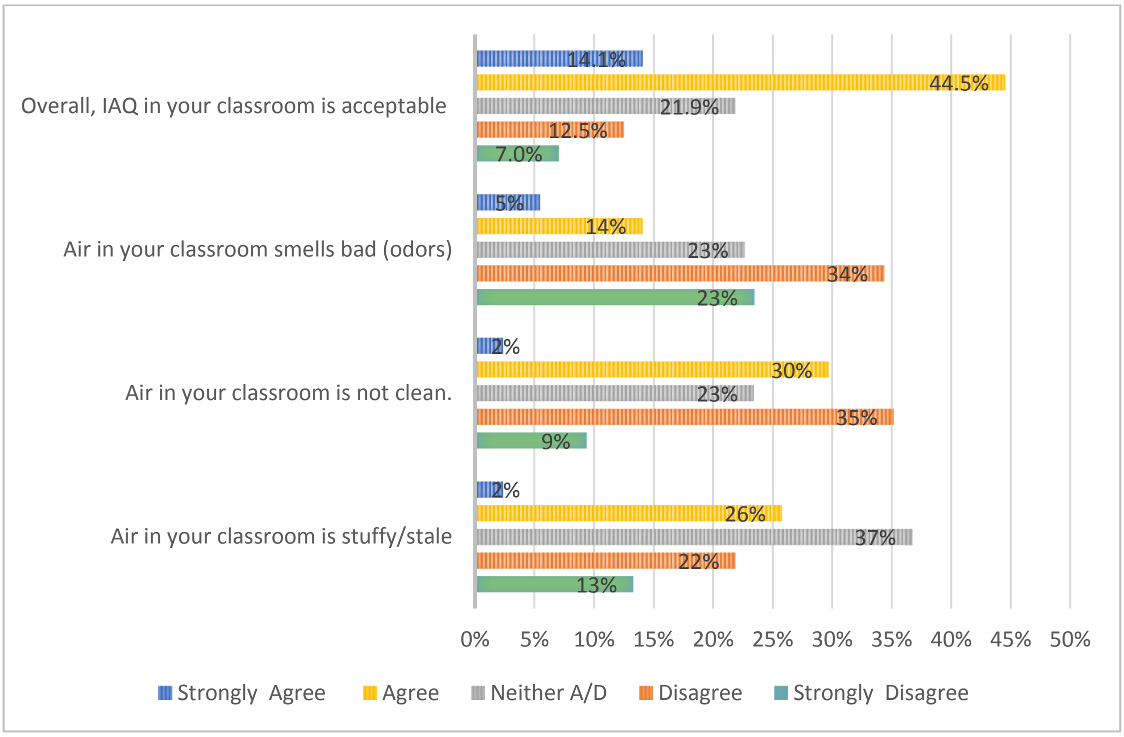


Figure 4.10: Indoor air quality in classrooms

4.5.4 Light quality

The participants were next asked for their level of agreement with five items on light quality. Figure 4.11 shows that responses on these parameters were generally positive, with the obvious exception of the item on daylight amounts, where respondents were almost equally divided among those who agreed that there was enough daylight in the room, those who disagreed and those who were neutral. On the other items, between 50 and 60 percent agreed that artificial light levels were adequate, that glare and reflection were at comfortable levels, that they had an acceptable ability to control the amount of light and that the overall lighting quality was acceptable. Negative responses accounted for about a quarter of answers to the items on overall lighting quality and visual condition, while 16% thought artificial light was inadequate and only half as many were dissatisfied with controllability.

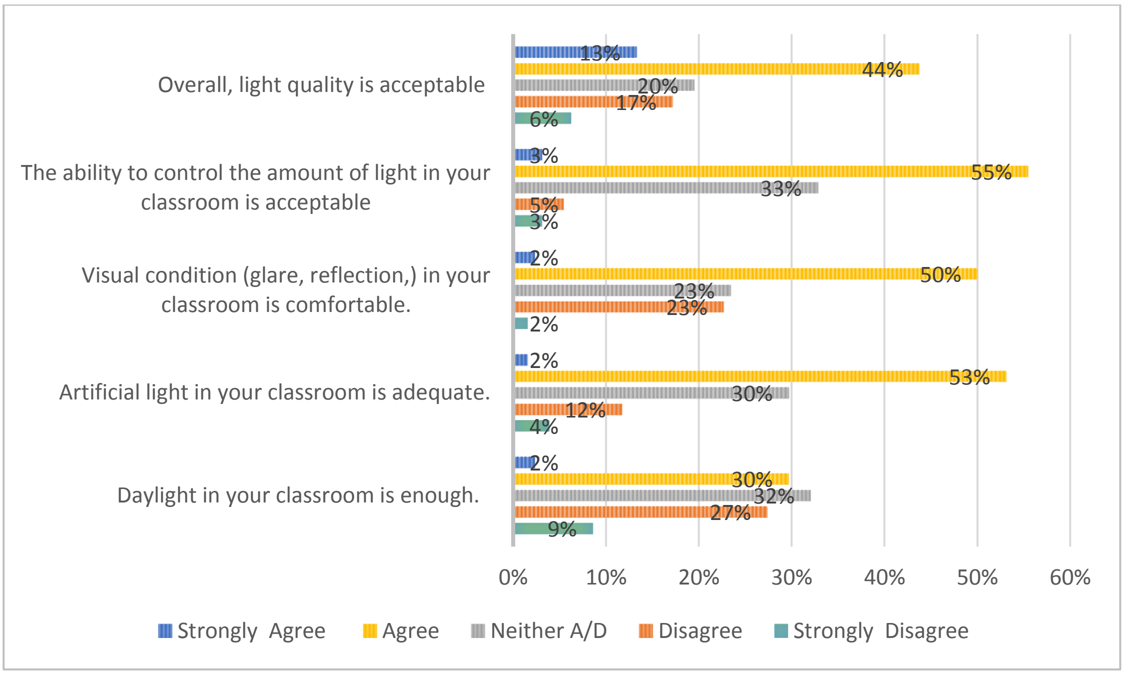


Figure 4.11: Light quality in classrooms

When participants were asked how light amounts were controlled in their classrooms, two thirds stated that this was by means of light switches and one third replied that they used window blinds or shades (Figure 4.12).

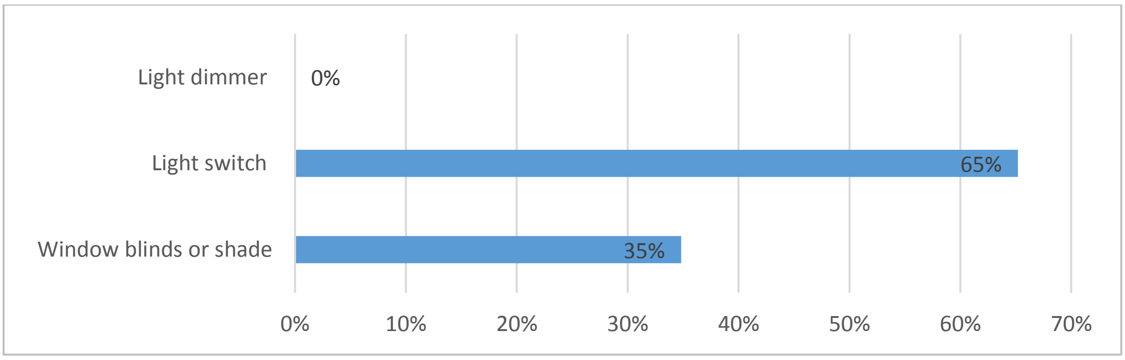


Figure 4.12: Methods of controlling light amount

4.5.5 Acoustic quality

The final category of environmental factors which teachers were asked to assess was that of acoustic quality. Overall, almost half of respondents considered acoustic quality unacceptable and only a quarter found it acceptable, as Figure 4.13 shows. The remaining four items concerned specific sources of noise. Two thirds of teachers identified neighbouring classrooms as causing noise and 45% blamed the HVAC system. In contrast, teaching equipment and external sources such as traffic were identified as noisy by only 18% and 10% of respondents respectively.

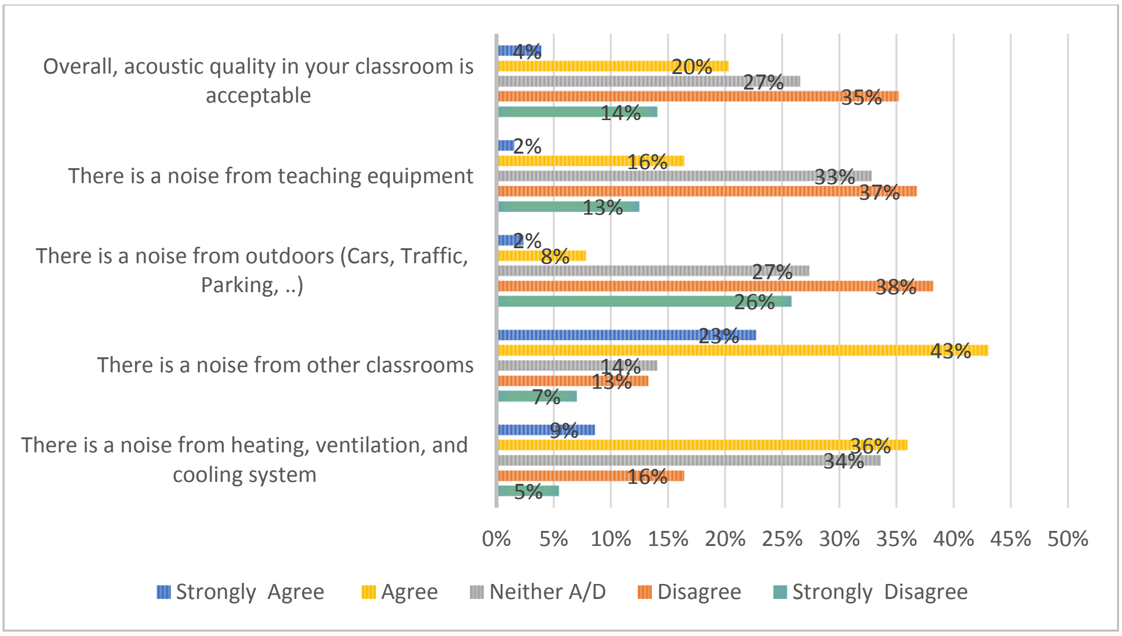


Figure 4.13: Acoustic quality in classrooms

4.5.6 Effects of IEQ on wellbeing

The next part of the survey assessed the effect of indoor environmental parameters on teachers' wellbeing. Figure 4.14 indicates that three variables, namely IAQ, thermal comfort and illumination level, were perceived to have strongly positive effects on wellbeing, with positive responses of 69%, 63% and 60% respectively. On all of these items, neutral responses of around 20% outnumbered the negative ones. Perceptions of the effects of layout and of view and biophilia were also broadly positive, at 43% and 48% respectively, with 30%

neutral responses and only 28% and 21% of participants perceiving a negative effect. As to acoustic quality, classroom furniture and colour/texture, approximately equal numbers of teachers gave positive, negative and neutral responses to all of these items.

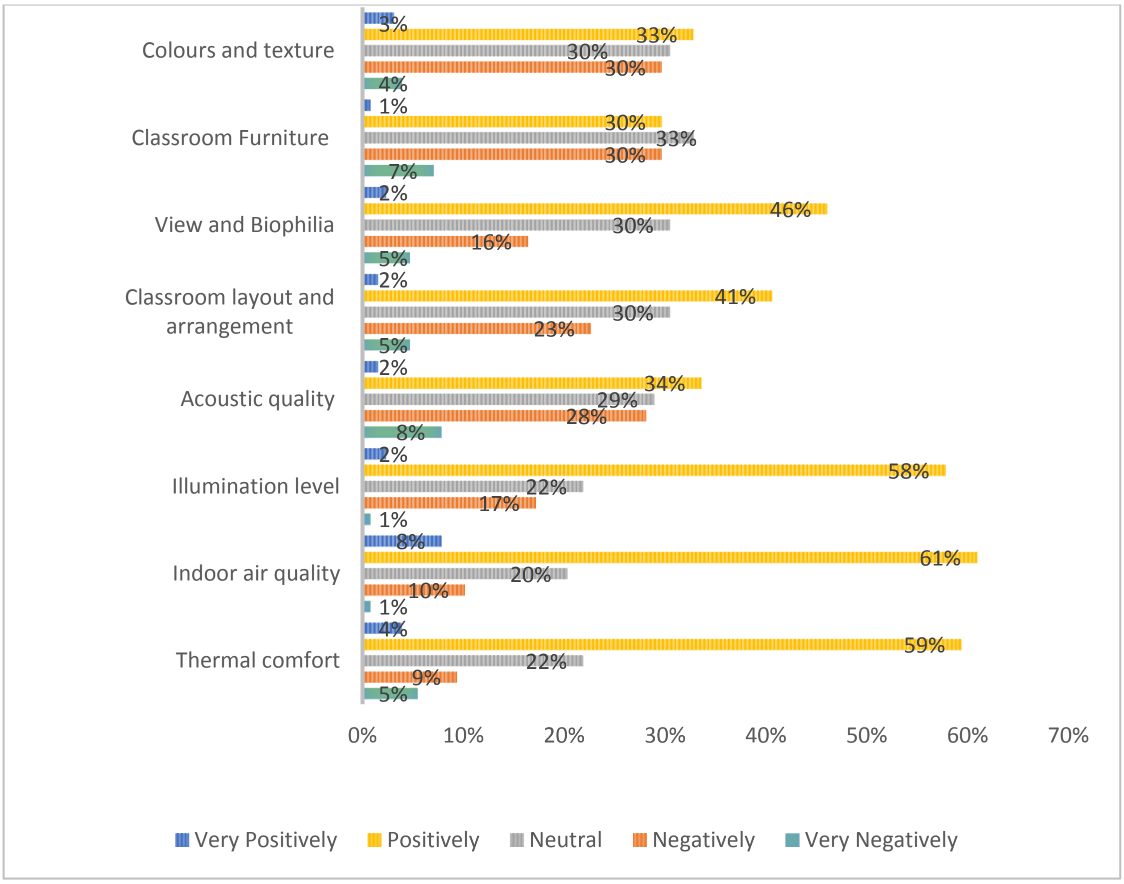


Figure 4.14: Effects of indoor environmental quality on wellbeing

4.5.7 Effects of IEQ on performance

Finally, teachers were asked to assess the effects of the same eight factors on their teaching performance. All of the factors except acoustic quality were reported to affect performance positively to some degree, the highest percentage being for thermal comfort, which 70% of teachers assessed positively while only 11% reported a negative effect, the lowest negative response in this set of items. IAQ had the second highest positive effect at 65%, followed by light quality and view, which were above 56%, while classroom arrangement, furniture and colour/texture (look and feel) evoked 44% to 46% of positive responses. As to acoustic quality, responses were again (as with effect on wellbeing) divided more or less evenly among positive, negative and neutral effects (Figure 4.15).

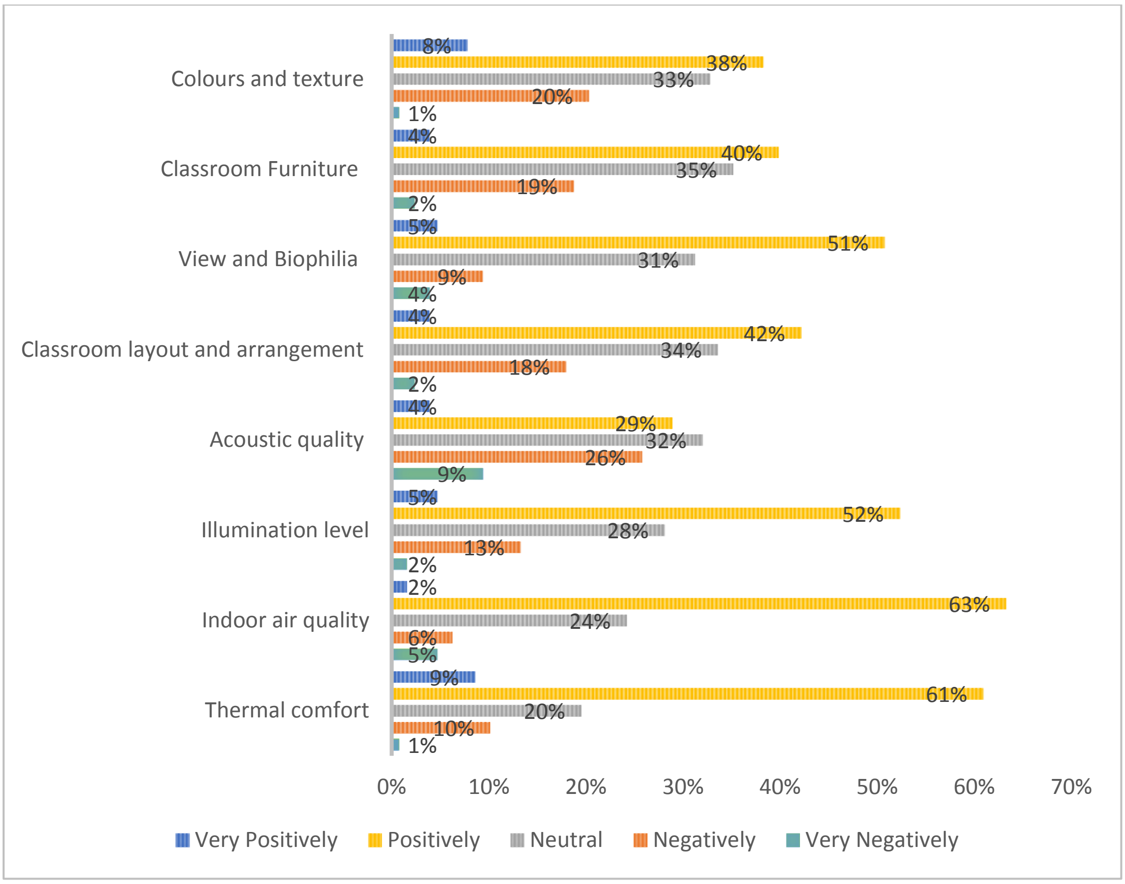


Figure 4.15: Effects of indoor environmental quality on performance

4.6 Conclusion

This chapter has reported the descriptive analysis of data collected in classrooms by instrumental measurement, questionnaire survey and observation, presented here by means of the appropriate diagrams and charts.

The measurements of physical indoor environmental parameters were recorded in selected classrooms at JTC while the HVAC system was running and the rooms were occupied with ongoing classes. Temperatures were measured in the range of 21.5 °C to 26.5 °C, while the outside temperature was above 33 °C. It was found that 84% of all temperature readings in 124 classrooms were within the recommended range, as were 87% of CO_2 measurements and 88% of light measurements. In contrast, the operation of the HVAC system was perceived as a source of unacceptable noise by a large proportion of questionnaire respondents. The records also showed that only 58 classrooms met the standards for noise level, whereas 114 met the standards for relative humidity.

Demographically, most participants were aged between 31 and 50 years, two-thirds had worked at JTC for more than five years, almost half had 16-20 teaching hours per week, half were qualified to master's level and 38% had 21-25 students per class.

The subjective survey of comfort with classroom conditions not measured instrumentally indicated general satisfaction, in that 59% of teachers were comfortable with classroom size, 58% with classroom layout, 54% with colour and texture, 46% with the number of students in the room and 39% with the furniture and equipment. As to degree of comfort with instrumentally measured IEQ factors, 62% were satisfied with thermal conditions, followed by IAQ (58%) and light quality (57%). However, only 24% considered acoustic quality acceptable.

Unsurprisingly, only 37% of teachers agreed that acoustic quality had a positive effect on their wellbeing, while the highest figure was 69% for indoor air quality. Perceptions of effects on performance were also mostly positive, with thermal comfort being seen as beneficial by 70% of respondents, in contrast to acoustic quality, whose effects more teachers rated negatively than positively.

These data, which were found to be of good reliability after inconsistent data had been excluded, were then used to create a statistical model, as reported in the next chapter.

Chapter 5

Development of the Assessment Model

This chapter highlights the use of artificial neutral network (ANN) modelling as a valuable tool to solve the complexity of relationships between performance and IEQ parameters. The analysis identifies the degree and nature of the interrelationships between 16 factors of IEQ input as independent variables and three dependent output variables, namely comfort, wellbeing and performance. This chapter reports the practical strategies adopted for using the ANN models developed to evaluate IEQ and performance. Finally, it compares the actual IEQ measurements with survey responses to determine the association between IEQ parameters and performance.

5.1. Introduction

An ANN is a computational model structurally composed of various processing features called artificial neurons, connected with coefficients and layers. The processing items have inputs, transfer functions and outputs for processing information.

The neural network in this research was trained with inputs, hidden layers and targets, with the ability to learn. A multilayer perceptron (MLP) network and backpropagation (BP) learning algorithm was implemented. Input data were fed forward through the network to adjust the weights between neurons, whereas backward propagation was used to correct the error of weights during the training phase.

The training inputs were the measurements of 16 variables: parameters of the physical indoor environment such as temperature, humidity, ventilation flow rate, CO_2 concentration, light conditions and sound level, as well as survey participants' demographic data. The three output layers were comfort, wellbeing and performance, whose associations with IEQ were explored. There are eight batch training algorithms in the MATLAB software package; these were investigated to determine which was most suitable to create a primary model for the research data. Developing ANN models is an essential part of this research to determine the relationships between input and output data, due to the complexity of the associations between the physical variables of the indoor environment as well as users' perceptions of these parameters.

The model was developed in three stages, determining successively the numbers of neurons and layers, the momentum values and the gradient values, to optimize the model's performance before it was used to generate new data via standard deviation and mean values of input and output data. Log transformation functions were used for these data to normalize the skewness distribution so that good data would be generated by the final ANN model, then the SPSS software was used to compare the new output data with the original data, thus evaluating the efficiency of a model that might be used for other future data.

The data from the model were used to construct a classification scheme for indoor environmental parameters. The classification of survey responses to each IEQ parameter helped to quantify its effect on users' comfort, wellbeing and performance, to investigate the performance of the buildings and to support the making of decisions about their condition.

5.2. Artificial Neural Networks

Artificial neural networks combine a variety of the characteristics of biological neural networks connected with training and generalization. The typical structure of these processes includes weight alterations to simulate the weakening and strengthening of connections, and activation functions to model the firing of neurons in response to incoming stimuli. Weight decay is used as a regularization technique, to replicate the trimming of unused connection over time. Recent samples of “biologically inspired training include the sleep-wake exercise routine modelled on the process of memory alteration that happens in the human brain during sleep’’ (Hinton et al., 1995) and the property of depth arising from the interconnection of several layers of brain units, which has stimulated deep neural networks (Bengio et al., 2015).

In general, the architectural elements of ANNs are neurons, topology and weights. Neurons are classified functionally as input neurons, hidden neurons and output neurons. In term of biological neural networks analogy, input neurons can be regarded as equivalent to sensory neurons, while hidden neurons, which in ANNs do most of the computation, correspond to interneurons and finally, output neurons are equivalent either to motor neurons or to terminal neurons for subnetworks.

In ANNs, the input neurons are usually not involved in multiplication of the incoming signal. However, there are exclusions, such as in relational neurons, where layer of input neurons have been applied to create additional sets of items by enhancing original set features through computing process (Russell et al.,1995; Engelbrecht, 2007). On the other hand, the hidden layers and output neurons compute almost all of the ANN process. This is could possible by the topology, transfer functions and weights allocated to each of neurons in the hidden and output layers (Bishop, 1995).

The transfer function is consisted with input function, also referred to as weight function or activation function, which fundamentally computes a value from incoming signals, x = $(x_1, x_2, \ldots, x_n)$, and their connected weights, W = $(w_1, w_2, \ldots, w_n)$ (Fig. 5.1).

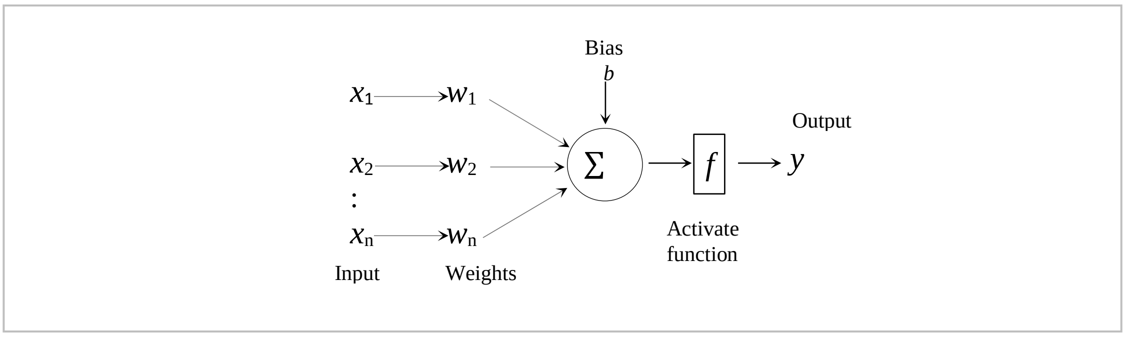


Figure 5.1: Data processing in an artificial neuron

There are a several of activation functions, some of the most popular being distance-based functions such as “Manhattan distance, maximum distance, Euclidean distance, and dot product-based functions such as the inner product’’ (Duch and Jankowski, 2000) Table 5.1 lists some of the common activation functions.

Table 5.1: *List of activation and output functions*

Activation function	**Output functions**
Inner-Product	Linear
Euclidean Distance	Step
Maximum Distance	Hyperbolic Tangent
Manhattan Distance	Sigmoid
Minkovski Distance	Gaussian
Cross-Product	Multiquadratic

In conjunction with the transfer function, there are output activation functions such as sigmoid and the hyperbolic tangent and Gaussian, which compute the outputs' neuron signal from the computed activation values. (Duch and Jankowski, 2001). The activation function and the output function enhance the transfer function to determine the type of transformation approach to signals from all other neurons. The topology has responsible for transmitting the signals produced, which expresses the connectivity between the neurons.

Stanley et al., (2003) determine that the most common topologies of ANNs are feed forward. A feed-forward topology connects all of the neurons in the previous layer to all of those in the next layer, consequently feeding the signals forward through the network (Fig. 5.2).

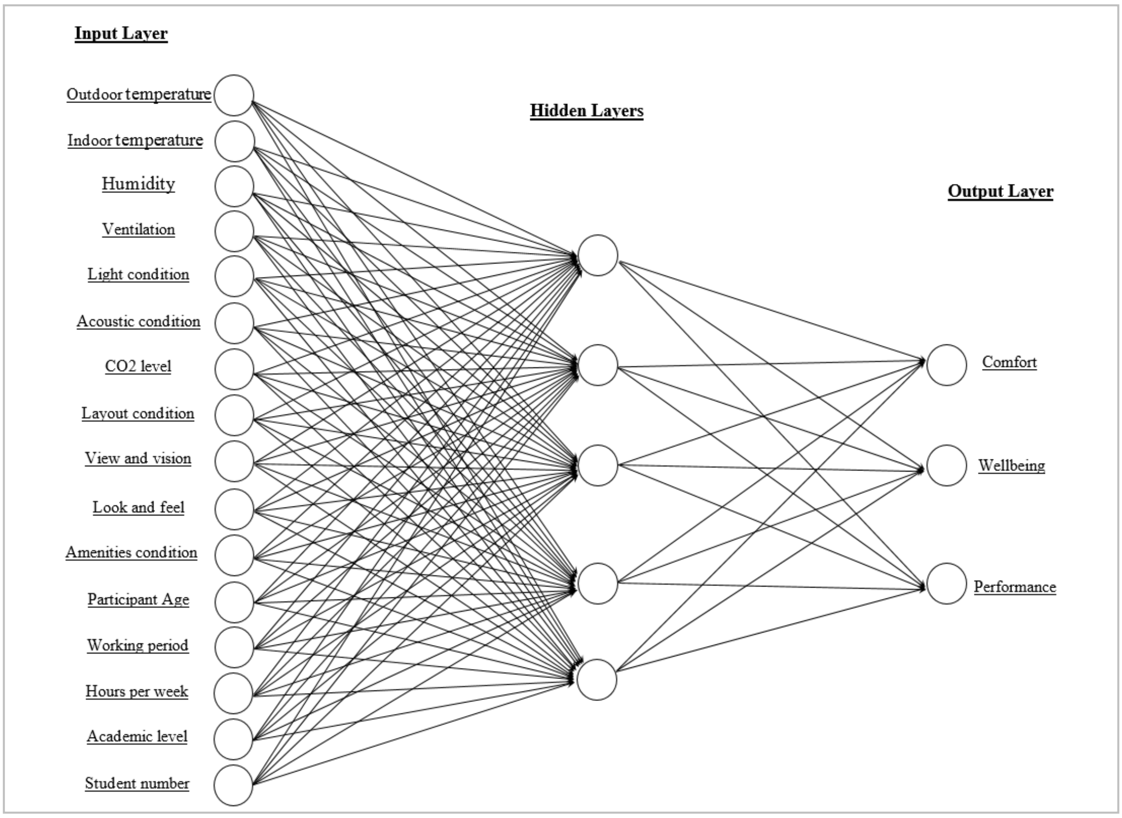


Figure 5.2: A feed-forward neural network topology for IEQ

Self-connection assists the neural network to have a deep and progressive structure, which provides it memory that is suitable for pattern recognition, where some setting of other trends is essential. However, topologies are not definitely confined to these sorts of connection, especially in ANNs, which have their topologies (Stanley et al., 2003; Gomez et al., 2008).

Learning in ANNs includes optimizing each features, such as by altering the weights, topology and transfer function. Generally, in terms of transfer function weight optimization, the weights of the neuron connections are iterated using learning algorithms to adjust the weights. Examples of the methods used in training algorithms are gradient-based ones such as the least mean squared (LMS), backpropagation and evolutionary algorithm (EA) approaches (Castellani and Rowlands, 2009; Billings and Zheng, 1995). In both cases, a statistical value of a mean squared error (MSE) determined the efficiency of the dataset.

5.3. Network Structure

An ANN is a computational model inspired with biological interactions, which consist of various processing features, represented as artificial neurons or single units. These are linked with coefficients that build the neural structure (Haykin, 2009). When processing data, the processing features have weighted inputs, transfer functions and outputs. Expressed mathematically, each neuron *i* sums its weighted input as follows:

$$net_i = \sum_1^n w_i . x_i \qquad (1)$$

where $x_i = (x_1, x_2, ..., x_n)$ represents the n input applied to the neuron and $w_i = (w_1, w_2, ...w_n)$ represents the weights for input x_i.

There are several types of neural network with many structures, which can be described in terms of the transfer functions adjusted in the processing features (neurons), the training algorithm and the connection formula. An ANN is structured of a multiple layers or single layer of neurons. MLP is a credible model for default problems, because it overcomes the weakness of the single-layer perceptron via increasing the hidden layers. In a feed-forward MLP network, the input signals are maximized by the connection weights before a direct activation function to set the output value for that neuron (Bishop, 1995).

The activation (transfer) function is implemented on the weighted sum of the neuron's inputs. It is usually adjusted on an ANN to improve its efficiency, since adjusted decision restrictions are likely to product high efficiency of neural network models, which create appropriate training. The most widely utilized transfer functions are Gaussian functions, hyperbolic tangent and sigmoid. The ANN is trained with input and pair patterns of target with a learning capability that includes several different algorithms (Duch and Jankowski, 2001).

The feed-forward BP training algorithm is the one most often used for MLP networks (Rojas 1996). Inputs are fed forward within the ANN to augment weights between neurons. The weights are adjusted for the error by backward propagation type through training. The ANN delivers the input and output data in the training process and adjusts the value of the weighted connects to reduce the difference in value between output targets. Error is minimized through many training cycles denoted to as epochs, until the ANN specifies a level of accuracy. However, the number of layers and of processing components per layer significantly affect the competencies of the MLP (Alsmadi et al., 2009). A typical MLP neural network at least composes of three layers. The first is the input layer, representing the problem input factors with one neuron for each input item. The second is the hidden layer, operated to setup non-linear relationships between the factors. Finally, the output layer provides predicted values.

In this study, the output layer of the primary model has three neurons corresponding to the forecast result. The association between output y_t and input x_t is expressed by the following formula:

$$y_t = b_j + \sum_{j=1}^{q} w_j . f\left(bi + \sum_{i=1}^{p} w_{ij} . x_t\right) \qquad (2)$$

where b_j is a bias value between the input and hidden layers, w_j is the weight between the input and hidden layers (i = 0,1,2,…,p; j = 1,2,…,q), w_{ij} is the weight between the hidden and output layers (j = 0,1,2,…,q), bi is a bias value between the hidden layers and the output, p is the number of input neurons, q is the number of hidden neurons and f is a nonlinear activation function that supports the system to train nonlinear elements.

The model developed for this study uses the nonlinear and tangent-sigmoid activation functions (tansig):

$$f(x) = \frac{2}{1+e^{-2x}} - 1 \qquad (3)$$

The MLP is trained using the BP algorithm and the weights are adjusted. The learning function to reduce the square errors of the variance between the predicted output ($y_{t,p}$) and the desirable output ($y_{t,d}$) is represented thus:

$$\bar{y} = \sum(y_{t,d} - y_{t,p})^2 \qquad (4)$$

The processing of the network is achieved by BP and some models are trained with the algorithm giving the steepest descent, such as gradient decent with momentum (trainGDM), by this equation:

$$\Delta w_k = -a_k . g_k \qquad (5)$$

where $\Delta\ w_k$ is a vector of weight deviations, g_k is the present gradient and a_k is the training rate that regulates the length of the weight update. In order to avoid fluctuations and to minimise the networks' sensitivity to rapid alterations in the errors (Jang et al., 1997), the adjustment in weight is occurred based on the previous weight change by enhancing a momentum term:

$$\Delta w_k = -a_k . g_k + P . \Delta w_k - 1 \qquad (6)$$

where P is the momentum variables. The inclusion of momentum allows the algorithm to escape from small local error in the network (Ramirez et al., 2003). These mathematical equations have been used in a number of studies (e.g. Zhang and Friedrich, 2003; Singh et al., 2011; Gardner and Dorling, 1999; Haykin, 2009; Edwards, 2007; Leopold, 2016) to implement ANN systems in different fields.

5.4. Training Algorithms

Training algorithms have a number of batch forms, which are constructed to train a network. The three main forms of training algorithm and their eight training functions have been classified on the basis of the brain hematoma process. The following subsections discuss gradient descent algorithms, conjugate gradient algorithms and quasi-Newton algorithms (Ali and Smith, 2006).

5.4.1 Gradient descent algorithms

Gradient descent algorithms, which are the most common training algorithms, are constructed from a basic gradient descent algorithm and update weights and biases in the trends of the negative gradient of the activation function. The three examples discussed here are trainGD, trainGDM and trainRP.

5.4.1.1 Gradient descent backpropagation algorithm

TrainGD is a gradient descent local search technique, using adjusted weights in the descending gradient path. It is commonly used to measure output error and to calculate the slope of the error (Beale et al., 2010).

5.4.1.2 Gradient descent with momentum

The trainGDM algorithm is a steepest descent algorithm with momentum, which allows the responding between a network and the local gradient indicated by the recent error surface trends. It acts as a filter that ignores small changes in the error surface with the momentum of the network. The momentum develops a network that is stuck in a shallow local minimum (Beale et al., 2010).

5.4.1.3 Resilient backpropagation

The trainRP training algorithm is used to reduce the effects of the magnitude of the fractional derivative functions (Anastasiadis et al., 2005). The derivative is used to control the direction of the weights and to update the network, while the magnitude of the derivatives has no influence on the updated weight. Update values determine the size of the weight. The values of each bias and weight are elevated by the performance of the derivative function with a weight that has the same sign for successive iterations. The update value is reduced by the derivative function when the sign of the weight differs from the previous iteration. If the derivative is zero, the update value remains the same.

5.4.2 Conjugate gradient algorithms

The gradient descent algorithm is implemented to adjust the weights in the direction of the negative of the gradient in which the performance of activation function is reducing most rapidly. This does not certainly produce the fastest convergence. In conjugate gradient algorithms, a search is achieved along conjugate directions, which creates usually faster conjunction than steepest descent approaches. However, conjugate gradient algorithms require more machine storage space than other algorithms. Therefore, these algorithms are most suitable for networks with a large number of layers and weights (Hager and Zhang, 2006). The three examples considered below are trainSCG, trainCGF and trainCGP.

5.4.2.1 Scaled conjugate gradient

Unlike other conjugate training functions, trainSCG does not require a line search for every iteration step. The use of a step size scaling mechanism minimizes the search time per learning iteration, making the algorithm faster than any other training algorithms. The trainSCG function needs more iterations to congregate than other conjugate gradient algorithms, but the number of each search iterations is significantly minimized, since no line search is executed (Moller, 1993).

5.4.2.2 Conjugate gradient backpropagation with Fletcher-Reeves updated

The trainCGF algorithm calculates the differences in the ratio of the mean square of the current gradient to the mean square of the previous gradient. Conjugate gradient algorithms are generally faster than other algorithms, but the result the of problem solving depends on the data and problem type (Beale et al., 2010).

5.4.2.3 Conjugate gradient backpropagation with Polak-Ribière updated

TrainCGP is a conjugate gradient algorithm that measures the ratio of the inner outcome between the mean squared value of previous variations in the gradient and the mean square of the current gradient. The capacity storage for the Polak-Ribière model, which has four vectors, are larger than for Fletcher-Reeves (Demuth et al. 2008).

5.4.3 Quasi-Newton algorithms

Newton’s method mostly provides faster and better adjustment than conjugate gradient algorithms. Its fundamental step is considered to be the Hessian matrix with second derivatives of the performance signal at the current values of the biases and weights. Newton algorithm converges much faster than conjugate gradient algorithm, but for feed-forward neural networks, these algorithms are complex and take more time to be generated with the Hessian matrix. In the quasi-Newton or secant method, the second derivatives are not calculated and each iteration of the algorithm is only updated with an approximate Hessian matrix (Moller, 1993).

5.4.3.1 Broyden-Fletcher-Goldfarb

The Broyden-Fletcher-Goldfarb (trainBFG) algorithm approaches Newton's method and is classified as a “hill-climbing optimization technique’’ which seeks the static point of a function. For such problems, the optimal zero gradient is essential for the high proficiency of the network (MathWorks website, 2017). This algorithm requires more computer storage space than the conjugate gradient approaches, but fewer iterations are needed to converge the model. TrainBFG usually performs better, even in non-smooth optimizations.

5.4.3.2 Levenberg–Marquardt backpropagation

The trainLM algorithm contains the minimum of multivariate functions that can be classified as the sum of non-linear square functions. The iterative technique of trainLM works in a way that performance function will continuously be reduced in each iteration processes in the network. This property makes trainLM the fastest training method for networks of moderate data. TrainLM functions in a similar way to trainBFG and has problems of memory and running of computing processes, due to the calculation of the approached Hessian matrix and the gradient, which requires high machine quality (Pham and Sagiroglu, 2001).

5.5. Artificial Neural Network Data

Various studies have shown the ANN approach to be a credible method compared with classical modelling techniques, which are complex, need long calculation times and are sometimes totally unreliable (Tripathy and Kumar, 2008). ANN models also have better predictive abilities than linear regression modelling (Ling et al., 2004). The use of ANNs to model the relationship between IEQ and performance could produce results that are not easy to obtain by means of classical modelling techniques (Santos et al., 2012). Apart from reducing the whole time required, it is possible that the ANN technique will find solutions that may make the study of IEQ and performance more feasible and attractive.

For the present study, an ANN was constructed on MATLAB software, which is considered a credible method to solve the complexity of inputs and outputs. This programme contains several workspace windows, the main one being the data manager window, which consists of four toolboxes that are used to build the model. These are the neural network box (nntool), the import box, the create network box and the network box (Figure 5.3).

A questionnaire survey was conducted to evaluate teachers' comfort with their classrooms' IEQ and its effectiveness in terms of comfort, wellbeing and performance. Forty-two items were related to teachers' comfort with the IEQ components of thermal comfort, IAQ, acoustic quality, lighting conditions and other subjective variables.

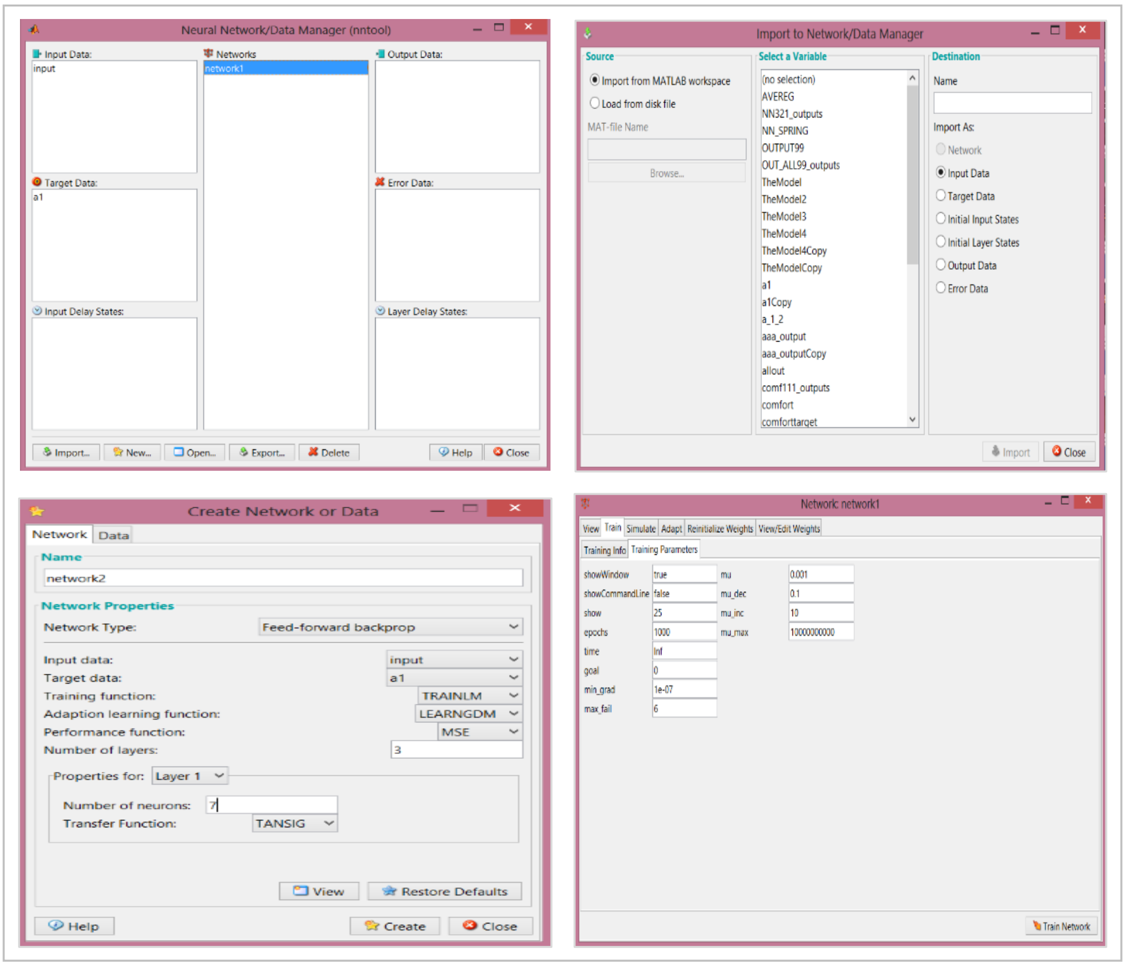


Figure 5.3: Data manager windows of the MATLAB network toolbox

Participants rated these variables on a five-point Likert scale. Figure 5.4 explains the method of ANN implementation to build an assessment model to investigate the association between IEQ and teacher performance.

The measurements of physical environmental parameters varied in the units used and values recorded; temperature ranged from 21.5 to 26.5 °C, humidity from 37% to 75%, CO_2 level from 590 to 1200 ppm, lighting from 244 to 450 lux, sound pressure from 44 to 77 dB and ventilation flow rate from 0.20 to 0.40 m/s.

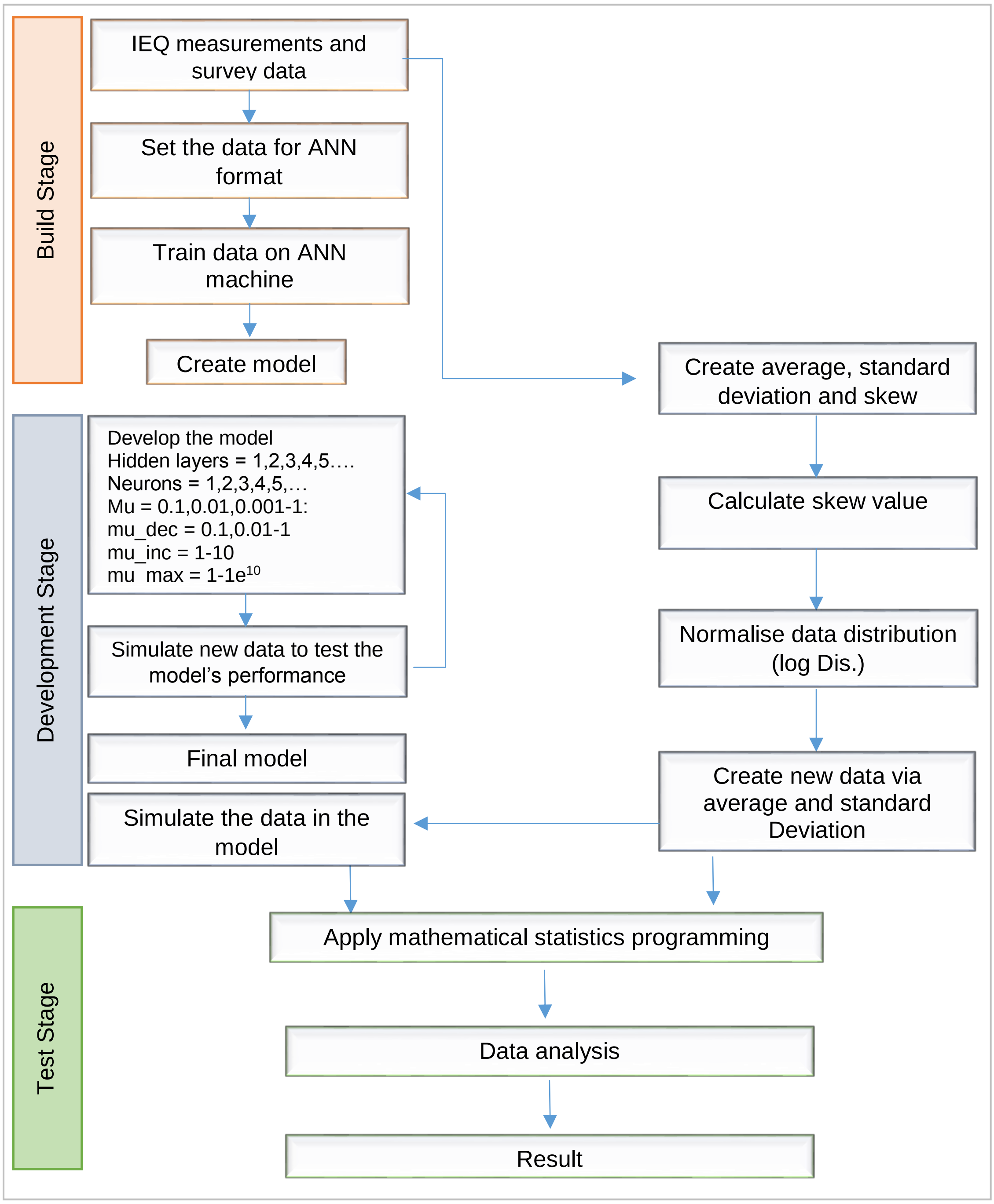


Figure 5.4: Design method for an artificial neural network model

To compensate these differences in the IEQ variables and survey scales, the data were normalized between -1 and 1 so that they were on the same scale, thus making the input and output variables comparable to each other, using this formula:

$$x = 2\frac{x - minx}{\max x - minx} - 1 \qquad (7)$$

Where x max= maximum observed value; $x$min=minimum observed value.

These data were used to generate new data from mean, skew, standard deviation and log transformation values, to address the efficiency of the final model and compare its result with traditional mathematical analysis on the SPSS software (Table 5.2). Azzalini and Capitanio (1999) state skewness is a “measure of the left-right symmetry of data distribution around the centre line. The skewness for a normal distribution is zero and any symmetric data usually have a skewness near to zero”.

Negative values of skewness indicate data that are skewed to the left, while positive values show that they are skewed to the right (Azzalini and Capitanio, 1999). Histogram charts are used to illustrate this property of the distribution of input and output data. Figure 5.5(a-c) shows histograms of IEQ parameters as input data, with comfort, wellbeing and performance as output, illustrating small positive skewness values.

Many methods have been developed to explore the normality assumption of experimental data. When the distribution of the data is non-normal, transformations of data are applied to make the data as normal as possible to increase the validity of the associated statistical analyses. Log transformation, which involves taking the natural logarithm of variables in a dataset, may help to fit a heavily skewed distribution into a more normal model. This is the most widely used method of transforming skewed data (Azzalini and Capitanio 1999). However, there is no guarantee that log transformation will reduce skewness and make the distribution of the data approximately normal (Ling and Liu 2004). The histogram in Figure (5.6) shows the normality and error of input and output data distribution for ANN logarithm training in all three phases of training.

	Input																Output		
	Outdoor Temperature	Indoor Temperature	Humidity	Ventilation	Light	Noise LVL	CO2 LVL	Layout	View	Looking	Amenities	Age	Work/ period	Hours/ Week	Education LVL	STD. NO	*comfort*	*wellbeing*	*performance*
Mean	28.15	23.6	53.02	0.275	424.6	56.25	790.1	3.168	3.212	3.209	3.255	38.22	10.09	16.04	2.003	21.79	3.557	3.541	3.524
Standard Deviation	3.262	1.132	7.34	0.158	62.81	6.007	118	0.804	0.753	0.769	0.789	7.459	6.845	3.817	0.65	3.281	1.165	1.098	1.128
Kurtosis	-0.218	0.45	-0.09	0.85	-0.09	1.25	0.976	0.54	-0.21	-0.28	-0.35	-0.08	-0.4	0.68	0.027	-0.59	0.96	0.89	0.97
Skewness	0.211	0.288	0.315	-0.16	-0.42	0.256	0.355	-0.13	0.37	0.33	-0.26	0.428	0.621	-0.52	0.204	0.043	0.284	0.311	0.242
Minimum	23	21.5	37	0.15	244	44.34	590	1	1	1	1	25	1	8	1	15	1	1	1
Maximum	36	26.5	75	0.4	540	77	1200	5	5	5	5	56	27	22	4	29	5	5	5
Log value	1.449	1.373	1.724	-0.27	2.628	1.75	2.898	0.501	0.507	0.506	0.513	1.582	1.004	1.205	0.302	1.338	0.551	0.549	0.547
Count	321	321	321	321	321	321	321	321	321	321	321	321	321	321	321	321	321	321	321

Table 5.2: *Statistical values of input and output data*

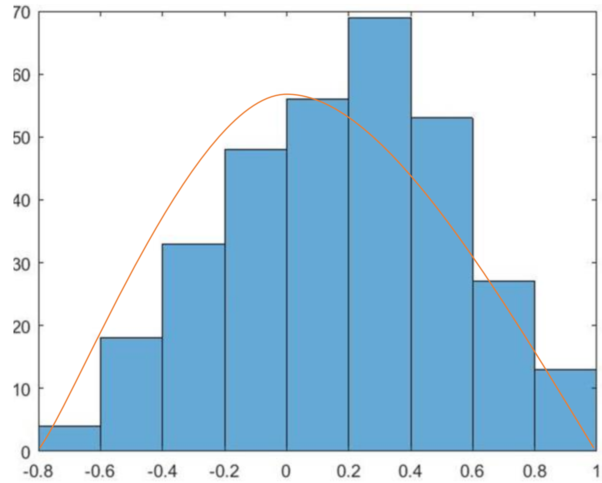


Figure 5.5 (a): Distribution of input data and output comfort data

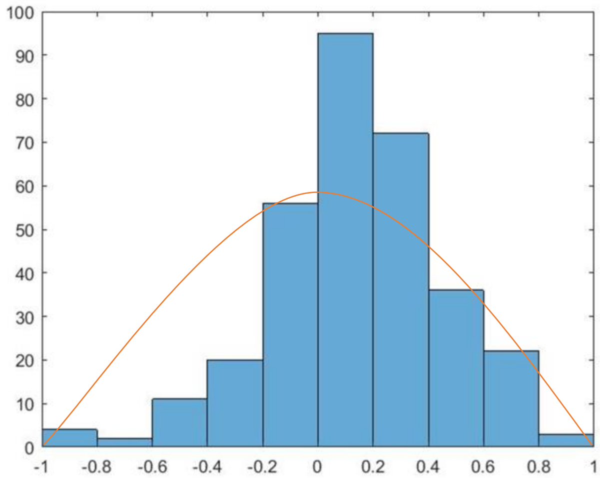


Figure 5.5(b): Distribution of input data and output wellbeing data

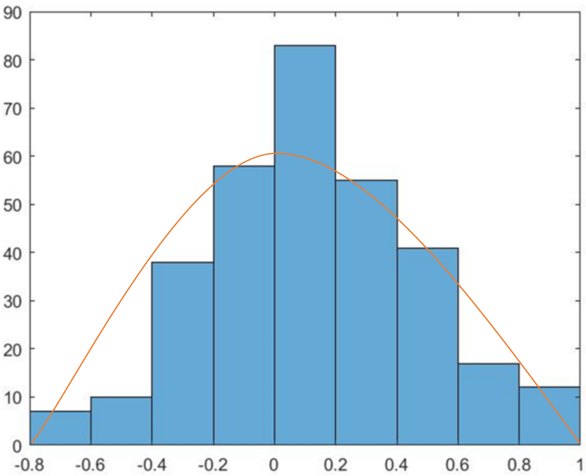


Figure 5.5(c): Distribution of input data and output performance data

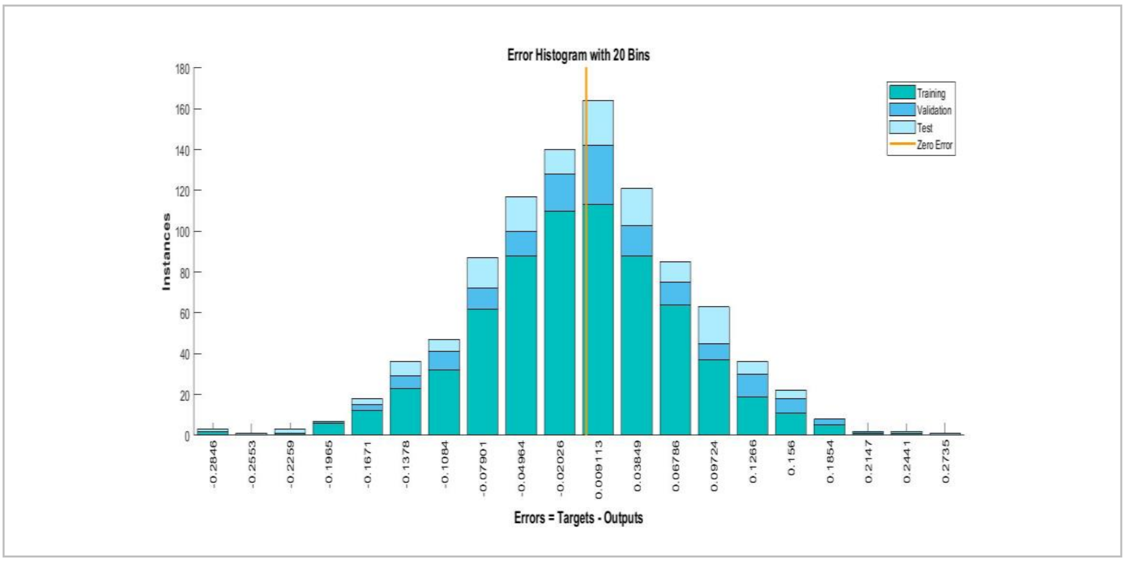


Figure 5.6: Histogram chart of data error and distribution with log transformation

5.6. Learning ANN Model

ANNs are increasingly seen as a powerful statistical modelling technique for use in scientific studies (Julian et al., 2004). The present ANN model was trained in turn with each of the three types of batch training algorithm identified in Section 5.4, to determine which was the most appropriate training algorithm. Eleven IEQ variables were included in the input layer: outdoor temperature (t_o), indoor temperature (t_i), humidity (h), ventilation flow rate (v), lighting condition, acoustic condition, CO_2 level, layout, view and visual, look and feel, and amenities. In addition, five demographic variables from the survey data (age, hours per week, educational level, number of students and period of working) were utilized as input parameters. The output layer consisted three neurons, related to comfort, wellbeing and performance (Figure 5.7). Thus, an ANN with two neurons and three hidden layers was built to construct a primary model, trained, tested and validated by MATLAB (R2017a) using nntool.

The presented datasets contained 321 input variables and their equivalent output factors from the measurement records, divided randomly into subsets for training, testing and validation. Seventy percent of the data were applied for training, 15% for testing and 15% for validation. Performance of the networks was evaluated by two standards: coefficient of determination (R) for the regression between observed and modelled values of the output variable, and mean square error (MSE) for the modelled values. (R) and (MSE) are expressed by the following formulas:

$$MSE = \frac{\sum_{i=1}^{n}(y_{p,i} - x_{o,i})^2}{n} \qquad (8)$$

$$R = 1 - \sqrt{\frac{\sum_{i=1}^{n}(x_{o,i} - y_{p,i})^2}{\sum_{i=1}^{n}(x_{o,i} - x_{\bar{o},i})^2}} \qquad (9)$$

where $x_{o,i}$ = input observed value; $y_{p,i}$= output predicted value; n = number of observations and $x_{\bar{o},i}$ = averaged observed values.

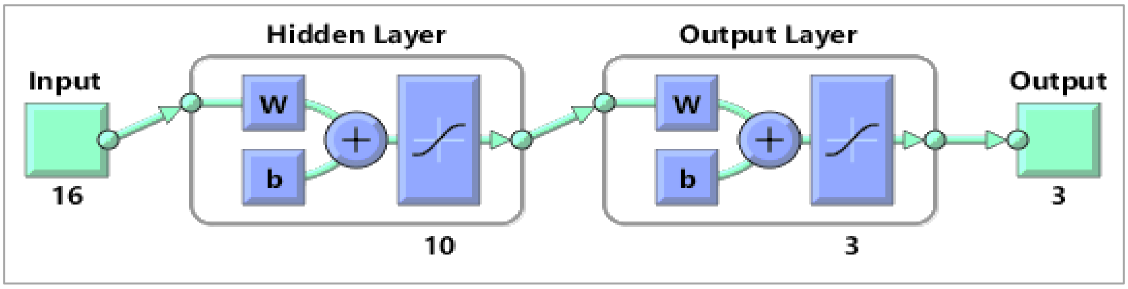


Figure 5.7: ANN components

In the primary model, the basic system training variables of maximum epochs = 1000 attritions, show = 25, performance goal = 0, time = Infinity, min_gradient (1-e^{07}), and max fail = 6 were static for each training function. The factors for comparison were regression (R) on training, testing and R on validation, MSE and number of epoch at the end of training. All of these variables were checked with the same number of neurons and layers as in the hidden layer topology. These experiments were first run with small number of neurons (N) and layers (L) (one neuron and one layer) for all trainings until the data were recognized, to explore the fastest and most appropriate type of training algorithm to be developed. The tansig transfer function was used for the hidden layer. Table 5.3 shows the number of epochs at the end of iterating process and the best validation concert (MSE) at epoch. In the training model, the convergence rate escalations and more epochs may require for training functions.

The ANN algorithms were evaluated by calculating two standard statistical performance criteria, the correlation coefficient R and MSE, allowing the selection of the most accurate and efficient algorithms.

Table 5.3: *Algorithm training results*

Algorithm	Training function	Transfer function	Best validation MSE	Epoch	R on training	R on validation	R on testing	All R	Gradient
Gradient descent	trainGD	tansig	0. 4284	153	0.6703	0.6958	0.6398	0.6681	0.2384
	trainGDM		0.8575	1000	0.5063	0.3717	0.4853	0.4848	0.0441
	trainRP		0.0550	15	0.7732	0.8303	0.7783	0.7827	0.0207
Conjugate gradient	trainSCG		0.1814	46	0.6253	0.7050	0.6307	0.6373	0.5399
	trainCGP		0.5375	7	0.4722	0.5667	0.6103	0.5096	0.0166
	trainCGF		0. 4681	6	0.4162	0.4076	0.4158	0.4141	0.0134
Quasi-Newton	trainBFG		0.0582	33	0.7454	0.7590	0.7536	0.7590	0.0181
	trainLM		0. 0497	77	0.8469	0.8186	0.7316	0.8277	0.0118

In Figure 5.8, the dashed line indicates the equivalent values of outputs and targets, data points are denoted by circles, and the solid line represents the best fit between outputs and targets. The circles are grouped along the dashed line, representing that the intimacy of output and target values.

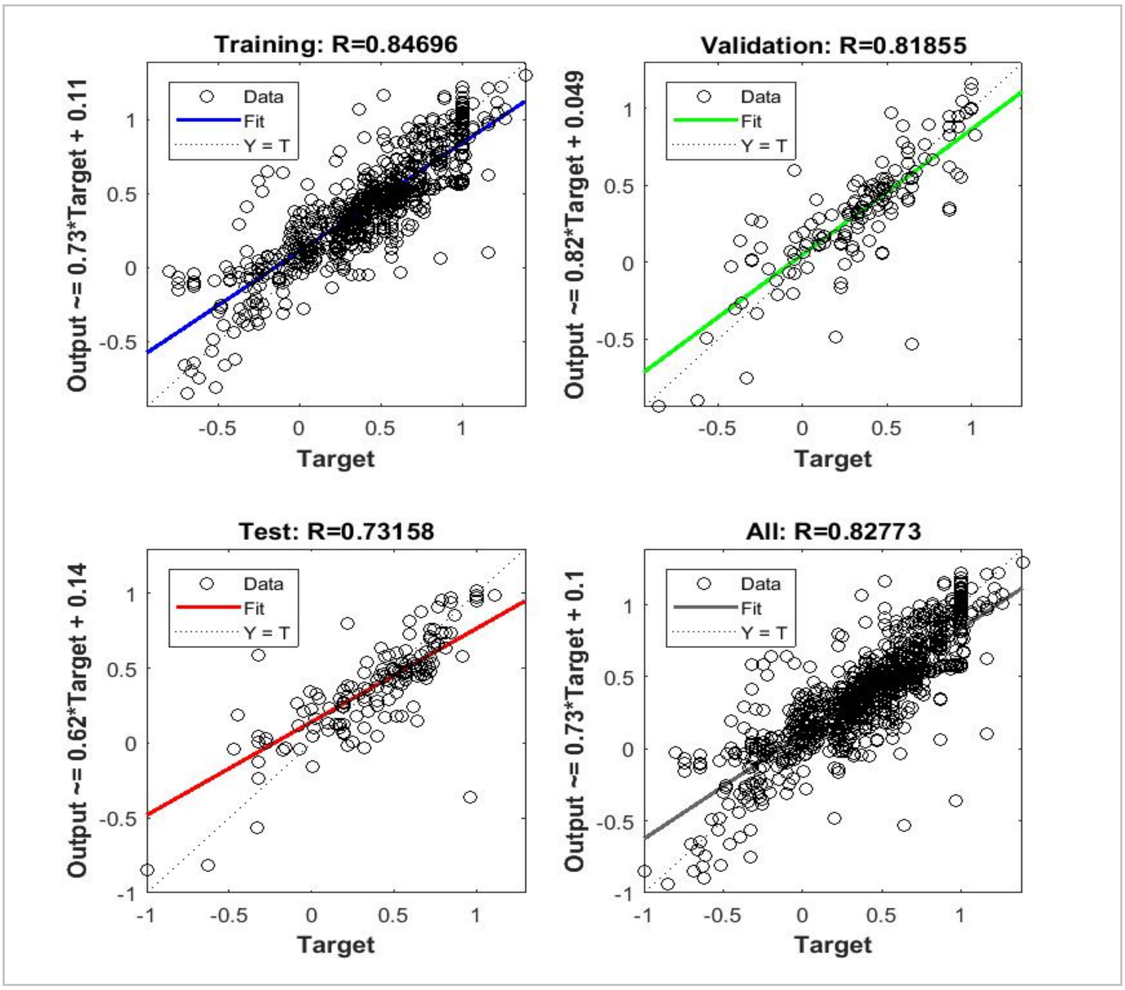


Figure 5.8: Correlation coefficient (R) on trainLM model

Several training algorithms were tested and the three highest scoring models were compared for the best values of R and MSE with two layers and three neurons. The highest correlation coefficient in the training phase was for trainLM, then trainRP and trainBFG, with respective values of 0.8469, 0.7732 and 0.7454. In the validation and test phases, trainRP had the highest values of 0.8303 and 0.7783 respectively. Although trainLM had the lowest value in the test phase, at 0.7316, its overall R value was the highest, at 0.8277, followed by trainRP (0.7827) and BF (0.7590). (See Appendix V for the test results of all experimental models).

The best validation performance among these algorithms on MSE value was 0.0497 at epoch 17 for trainLM over all of the modelling stages (Figure 5.9), followed by trainRP at 0.0550 and trainBFG at 0.0582. On the other hand, trainGDM, trainCGP and trainCGF had the lowest values of R on all evaluation criteria and the highest values of MSE, at 0.8575, 0.5375 and 0.4681 respectively.

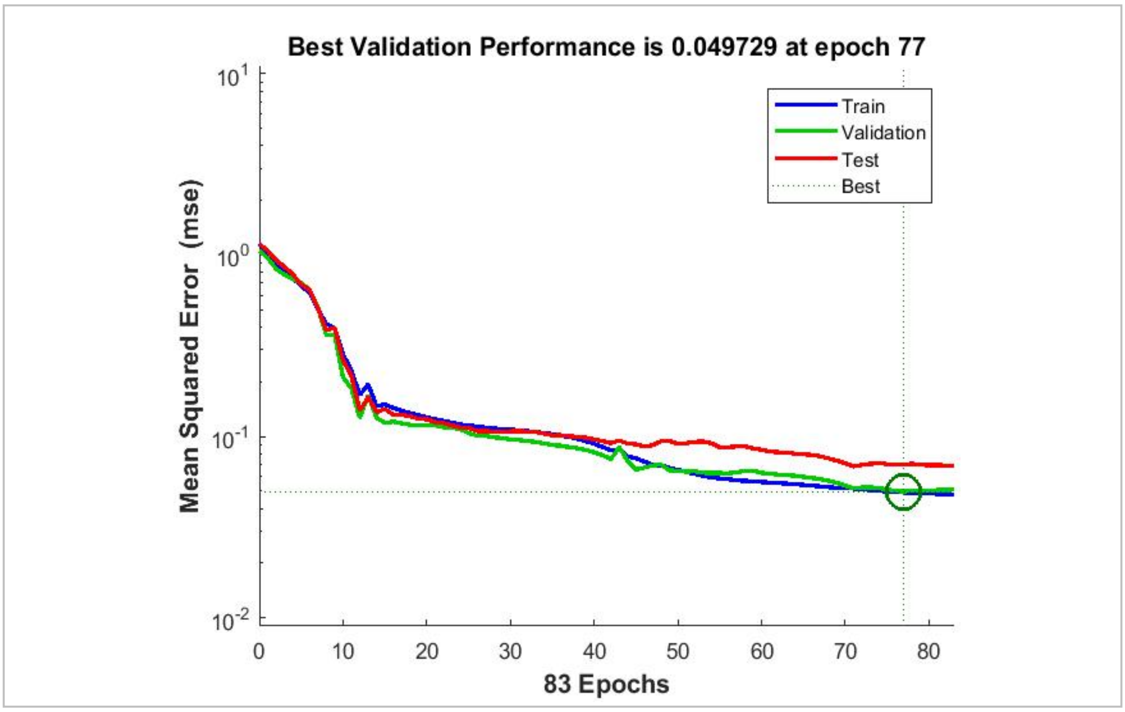


Figure 5.9: Best performance on trainLM algorithm

Gradient error represents variations in the value of μ. Validation checks of the training algorithms revealed gradients of 0.0118, 0.0181 and 0.0207 for trainLM, trainBFG and trainRP respectively, indicating that trainLM performed best.

Figure 5.10 shows that at epoch 13, the gradient error was 0.011807, μ was 1e-07 and there were six validation checks. The figure also shows that the training process was stopped because the minimum gradient error was reached at epoch 13, consistent with the following instructions on the MathWorks website (2017):

"TrainLM supports training with validation and test vectors if the network's property is set to a data division function. Validation criteria are used to stop training early if the network performance on the validation vectors fails to improve or remains the same for (max_fail) epochs in a row. Test vectors are used as a further check that the network is generalizing well, but do not have any effect on training".

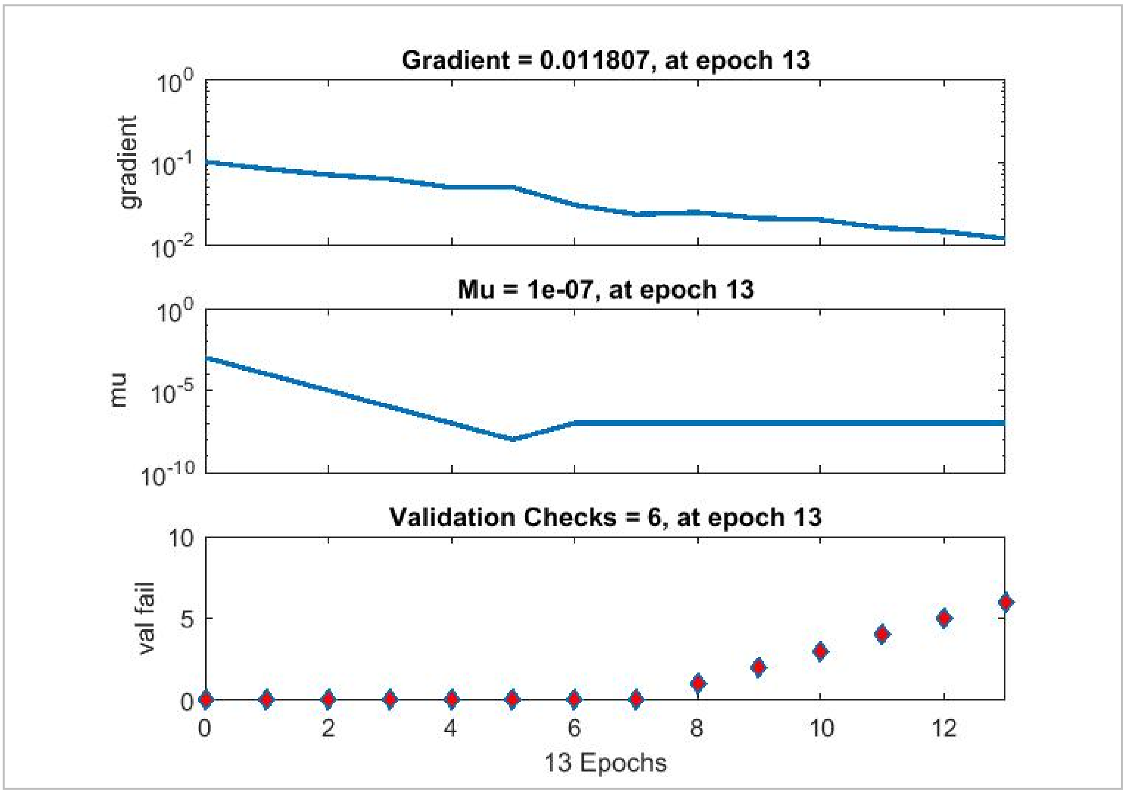


Figure 5.10: Gradient error of the trainLM algorithm

The above results indicate that the trainLM algorithm had the least MSE and gradient error with the highest value of overall R. These experimental findings identify trainLM as the best model to be used in developing the study model. TrainLM is generally the fastest BP algorithm in the toolbox and is highly recommended as a first choice for algorithm training, although it requires more memory than other algorithms (Quirchmayer et al., 2012, p. 37).

5.7. Developing the ANN Model

The trainLM algorithm was chosen as the primary model after testing the training algorithms most often used. The complexity of the models, as a function of the number of hidden layers and the number of neurons in each, should be considered when training a feed-forward ANN to develop a model. Many researchers have investigated the number of neurons required in a hidden layer to yield the best results, but the literature offers no agreed formula for calculating the optimal number of neurons and hidden layers to minimize network training time while maximising the accuracy of the target output (Karsoliya, 2012).

Among the various possibilities for optimising the number of neurons and hidden layers, Berry et al. (1997) suggest that the number of hidden layers and neurons should be less than twice the number of neurons in the input layer, while Rivals and Personnaz (2000) recommend that the number of neurons in the hidden layer should be between those of the input and output layers. However, neither of these suggestions can be considered to be always valid, because the number of neurons and layers is determined not only by the training algorithm and by the input and output layers, but also by the complexity of the activation function applied to the neurons (Karsoliya, 2012).

Levenberg-Marquardt backpropagation (trainLM) was found to be the most appropriate training algorithm for use in this study. The model was developed in three stages, as illustrated by the flow chart in Figure 5.11, beginning by optimising the number of layers and neurons in hidden layers to maximize the R value (as close as possible to 1) and minimize the MSE value (close to zero). Other criteria, such as momentum (mu = 0.001, mu_dc = 0.1, mu_inc = 1, mu_max = 1-e^5 and min_ grad = 1-e^5), were kept constant as defaults at this stage, until the best fitted model was found. The second stage was to take the final model from stage one and develop these values: mu = 0.0001-1 and mu_dc = 0.001-1, whereas mu_ inc = 1, mu_ max=1-e^5, and min_ grad = 1-e^5 were kept constant. The aim was to optimize these values to increase the efficiency of the model. The third stage was to develop the gradient by changing its value (1e^3 to 1e^{10}) in the model properties.

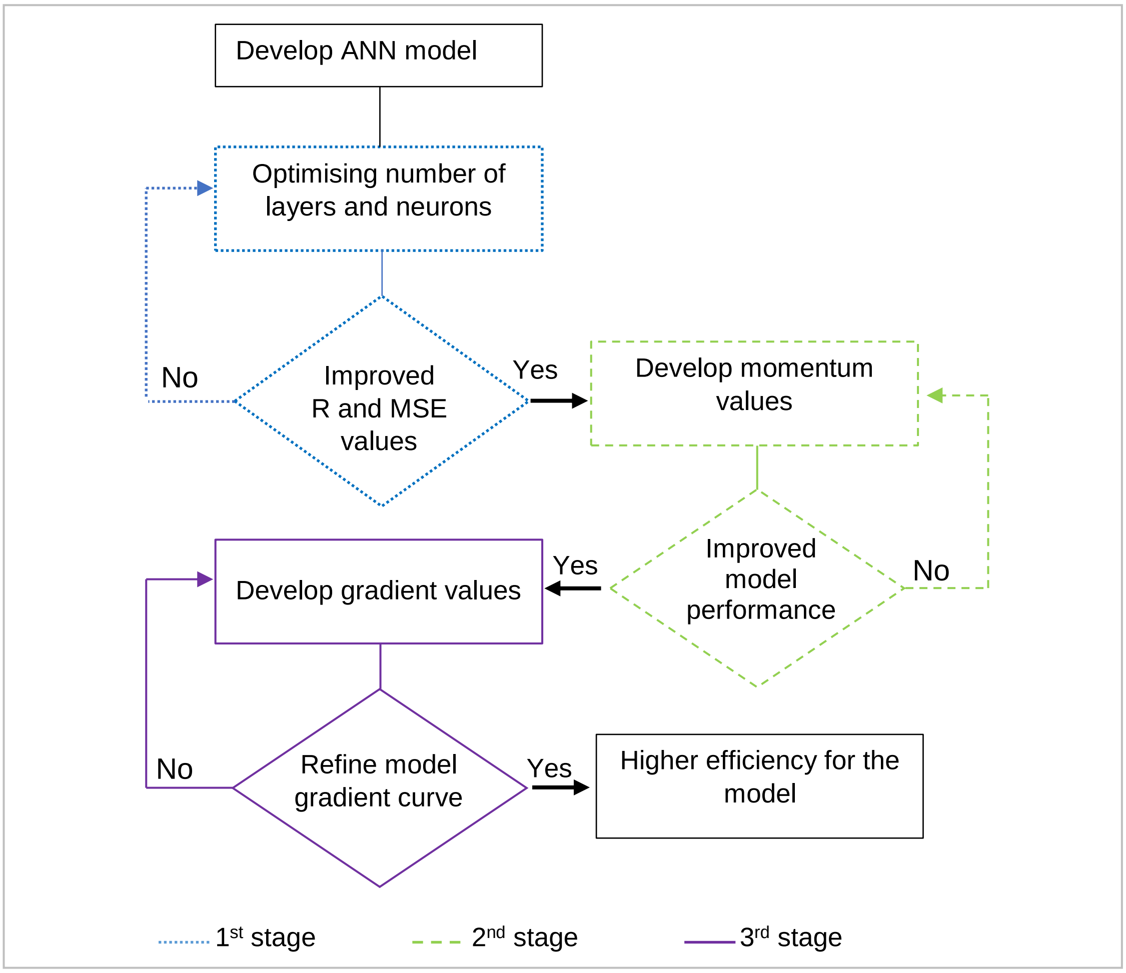


Figure 5.11: Flow chart of model development in three stages

The first stage can be considered the most important, because failure to create or improve a model with optimal layers and neurons would mean that the other two stages could not occur. Therefore, the model was developed by varying the number of hidden layers and neurons to maximize the R value and minimize MSE, in order to optimize the model's performance. The approach taken was based on the suggestion of Rivals and Personnaz (2000) that for a range of input and output sizes, the total number of neurons and hidden layers should be between three and 16, although larger numbers were tested to explore the accuracy of the model when it went beyond this range. Figure 5.12(a-h) compares the performance, R values and gradients of eight models varying in number of neurons and layers, where ANN 3-2, for example, is a network with three layers and two neurons.

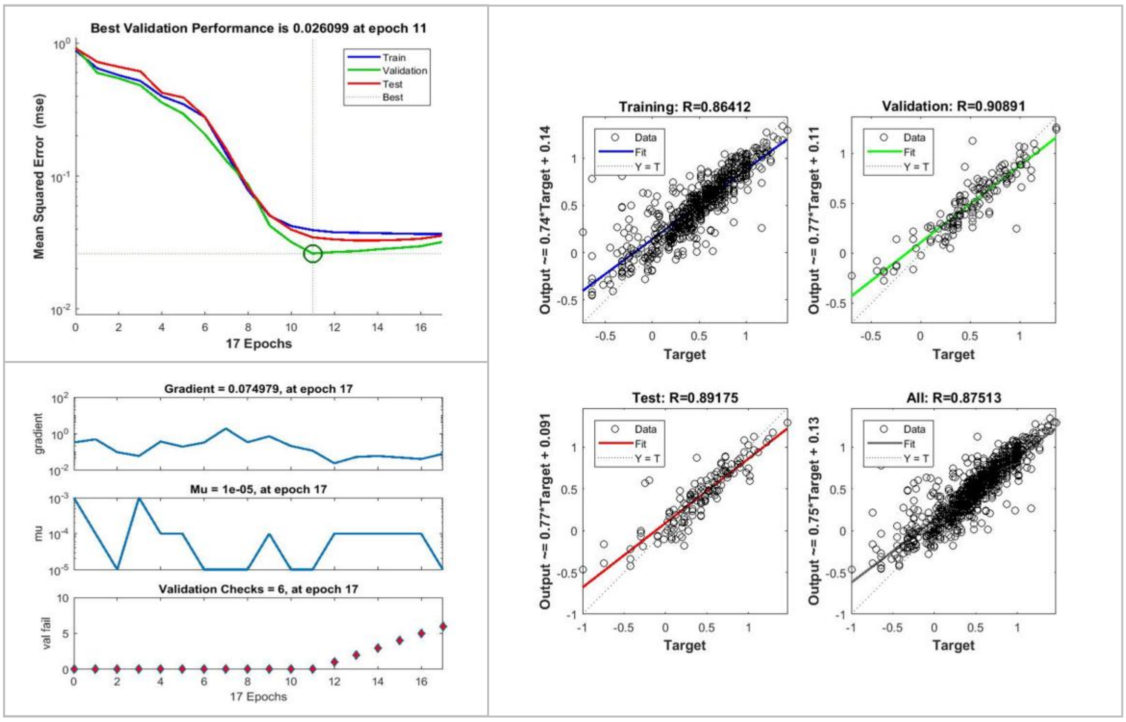


Figure 5.12(a): ANN 3L-2N

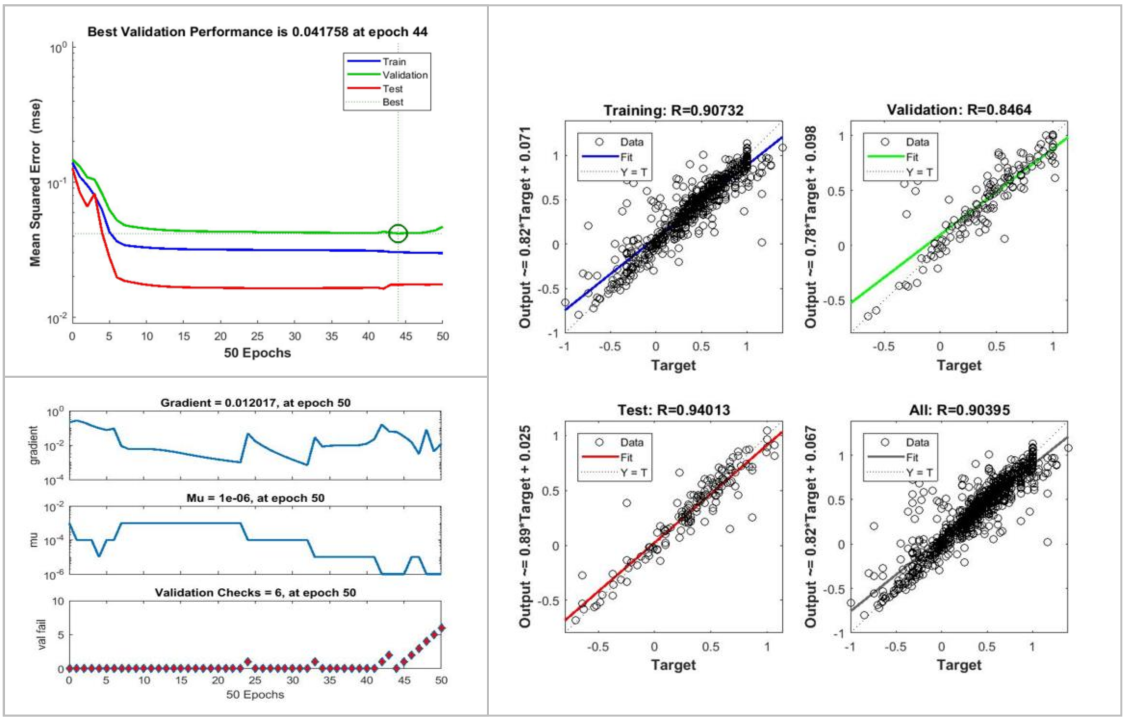


Figure 5.12(b): ANN 2L-5N

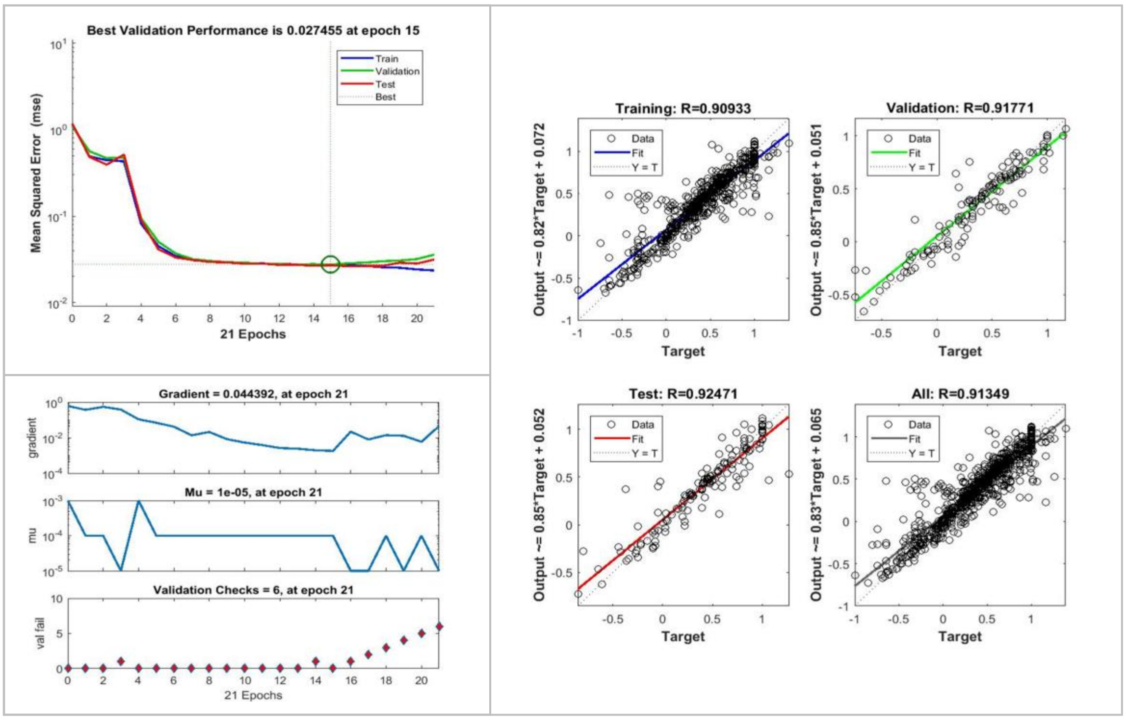


Figure 5.12(c): ANN 2L-9N

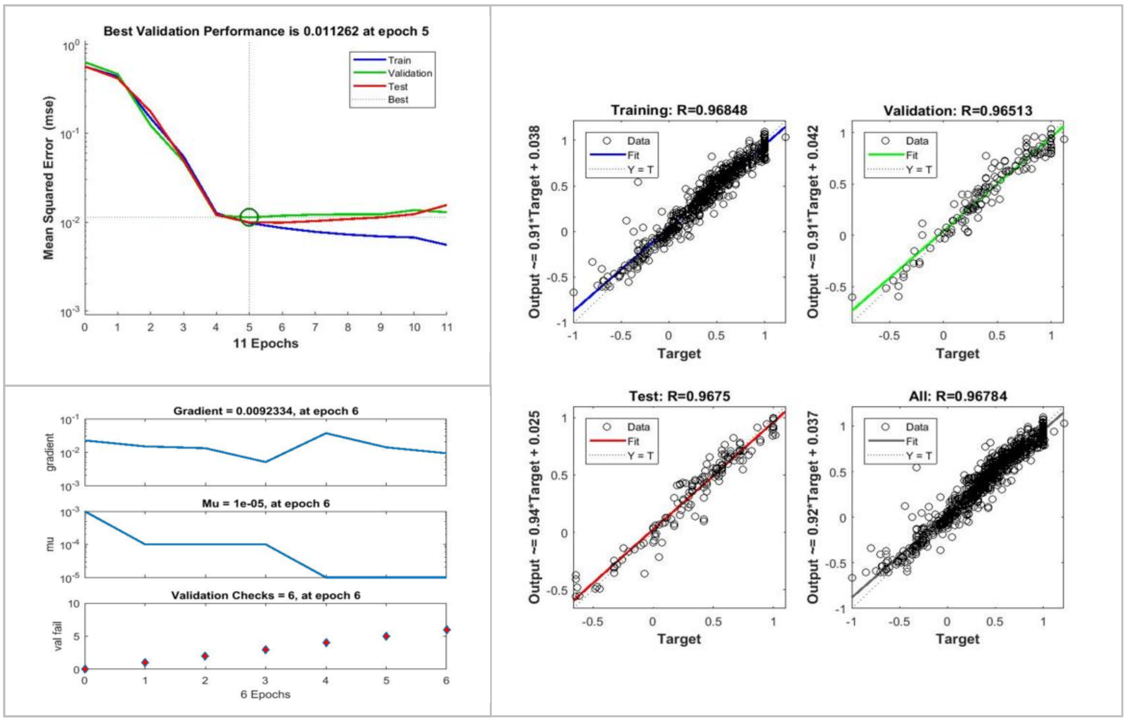


Figure 5.12(d): ANN 3L-5N

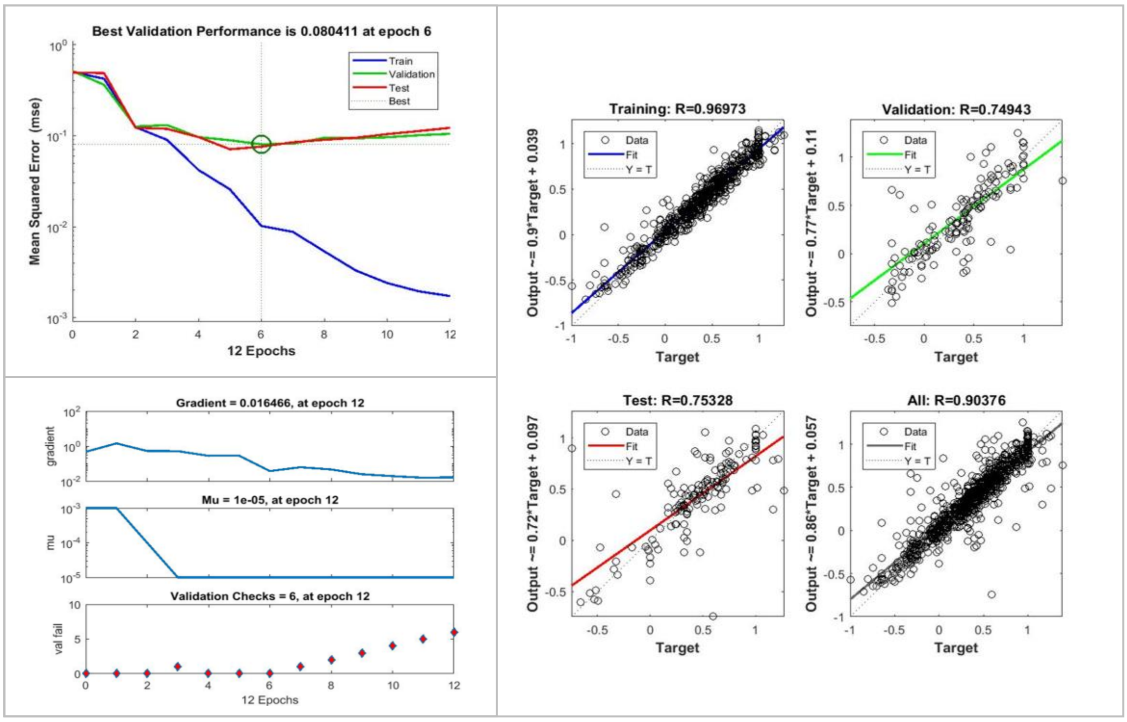


Figure 5.12(e): ANN 10L-10N

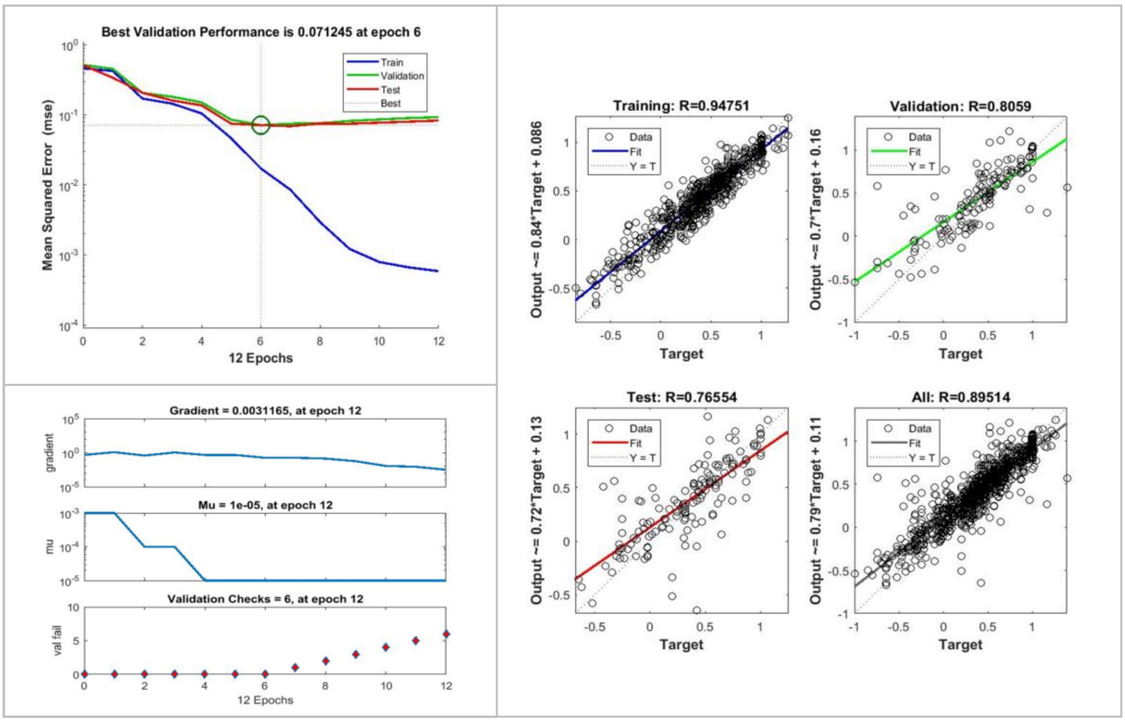


Figure 5.12(f): ANN 20L-20N

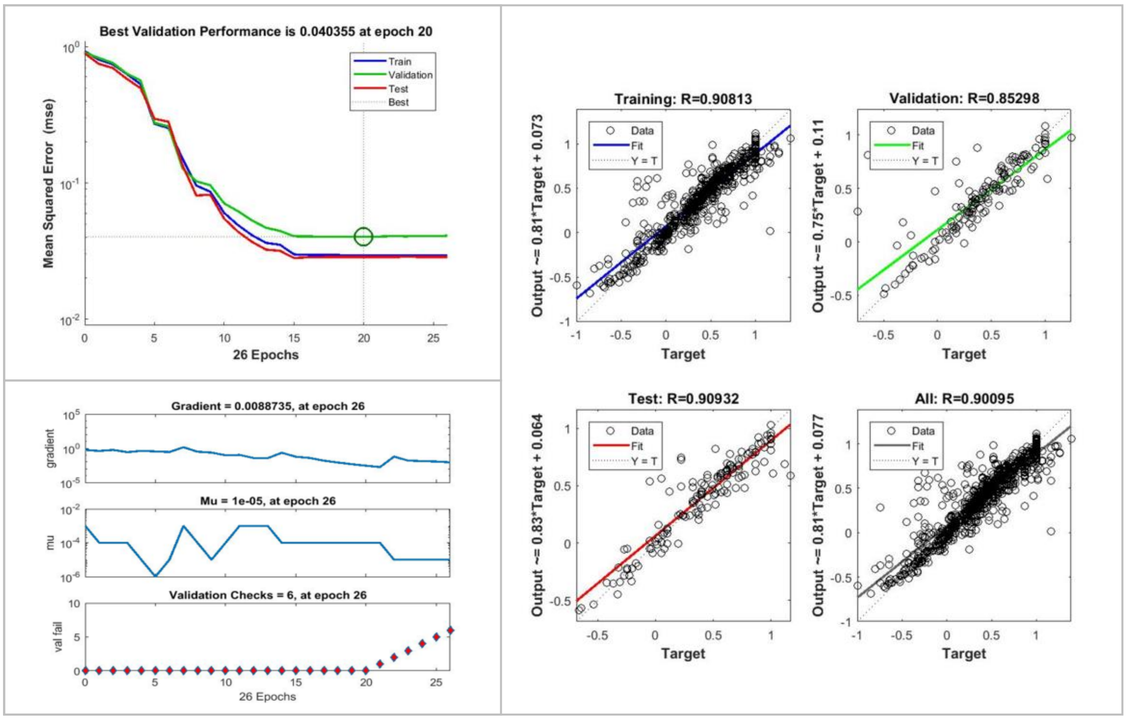


Figure 5.12(g): ANN 4L-7N

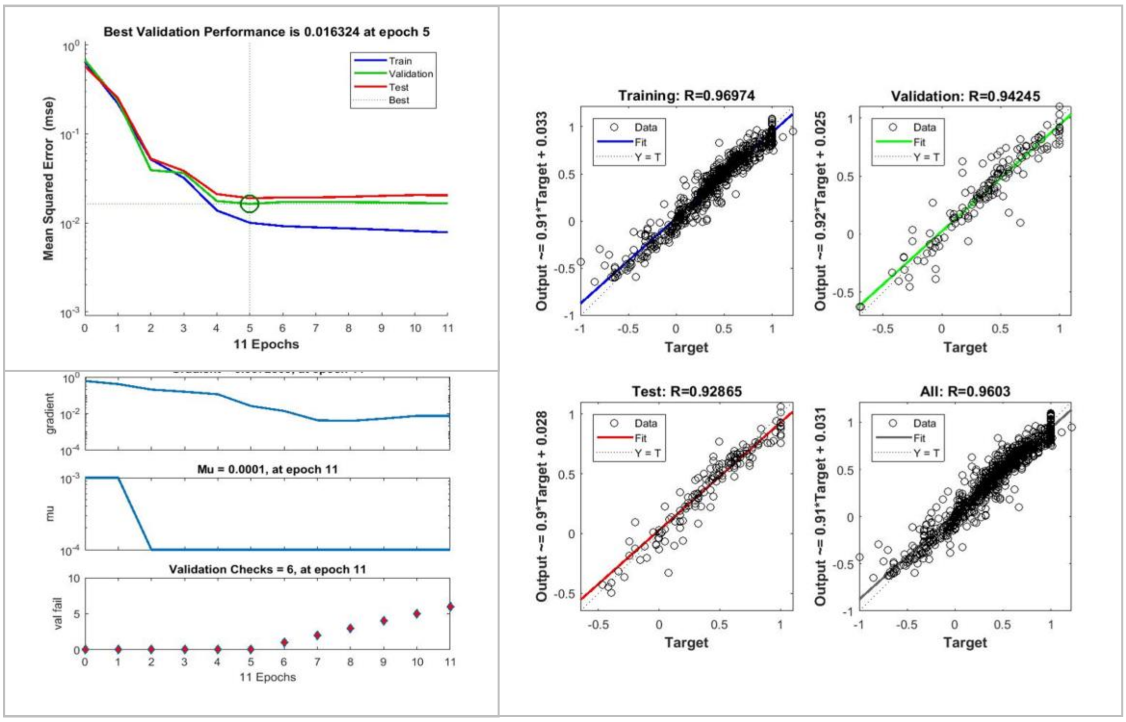


Figure 5.12(h): ANN 5L-8N

The values of R and MSE were improved by altering the number of hidden layers and neurons on training, validation and test for all trainLM models. Table 5.4 shows that ANN 3-5 (three layers and five neurons) was the best model, with the highest value of all R (0.9678) and the lowest value of MSE (0.0112). At this stage, the training model was constructed with small numbers of layers and neurons, which were gradually increased to large numbers if there was no development. However, when large numbers of layers and neurons were used, in ANN10-10 and ANN 20-20, no such improvement was seen, with all R at 0.9037 and 0.8951 respectively, whereas MSE values were relatively high, at 0.0810 and 0.0712 respectively.

Table 5.4: *Results of developing numbers of layers and neurons at 1ststage*

Model	Layers and neurons	MSE	R on training	R on validation	R on test	All R	Gradient
ANN 2-5	2:5	0.0417	0.9073	0.8464	0.9401	0.9039	0.0120
ANN 2-9	2:9	0.0274	0.9093	0.9177	0.9247	0.9135	0.0443
ANN 3-2	3:2	0.0260	0.8641	0.9090	0.8918	0.8750	0.0749
ANN 3-5	3:5	0.0112	0.9685	0.9651	0.9675	0.9678	0.0090
ANN 10-10	10:10	0.0804	0.9697	0.7495	0.7533	0.9037	0.0164
ANN 20-20	20:20	0.0712	0.9475	0.8059	0.7655	0.8951	0.0031
ANN 4-7	4:7	0.4030	0.9081	0.8530	0.9093	0.9001	0.0087
ANN 5-8	5:8	0.0163	0.9679	0.9423	0.9286	0.9603	0.0073

The second stage was to improve the performance of model ANN 3-5 by developing its momentum. Mu typically ranges between 0.0001 and 1 whereas min_ grad were kept constant as 1-e5. Here, various values were used to improve the model. Figure 5.13(a-f) is a series of charts showing the extent to which various mu values increased the R values and minimized the MSE values to improve the performance of the model.

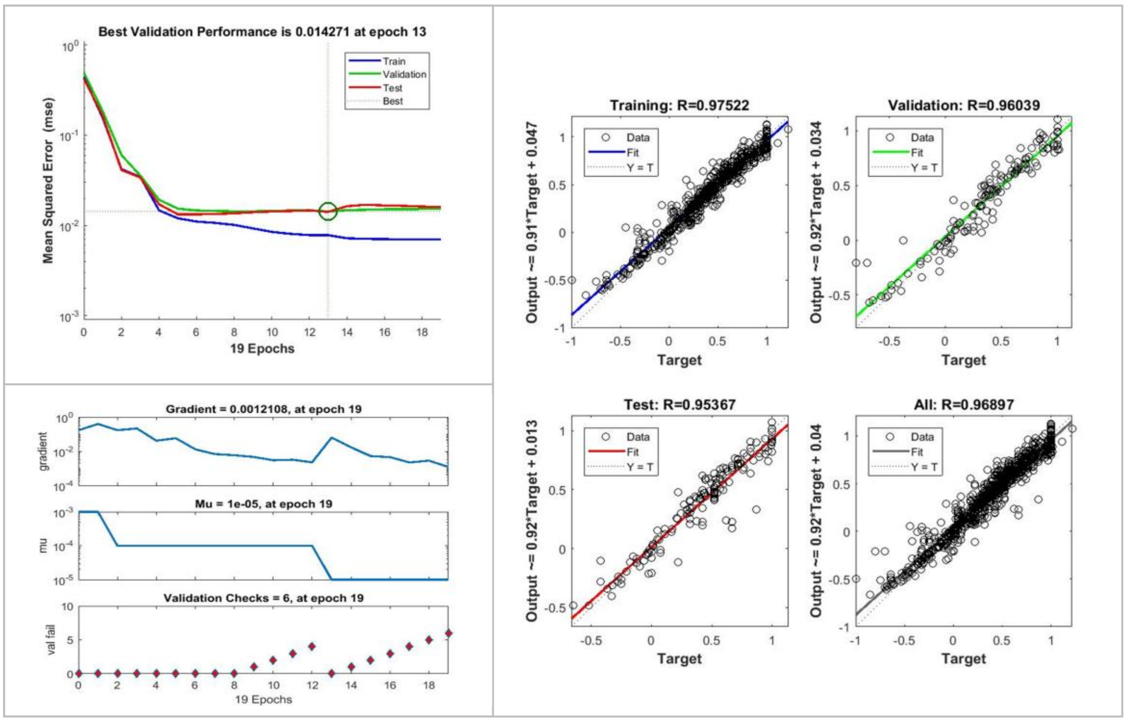


Figure 5.13(a): ANN3-5-1 (mu 0.001:0.01)

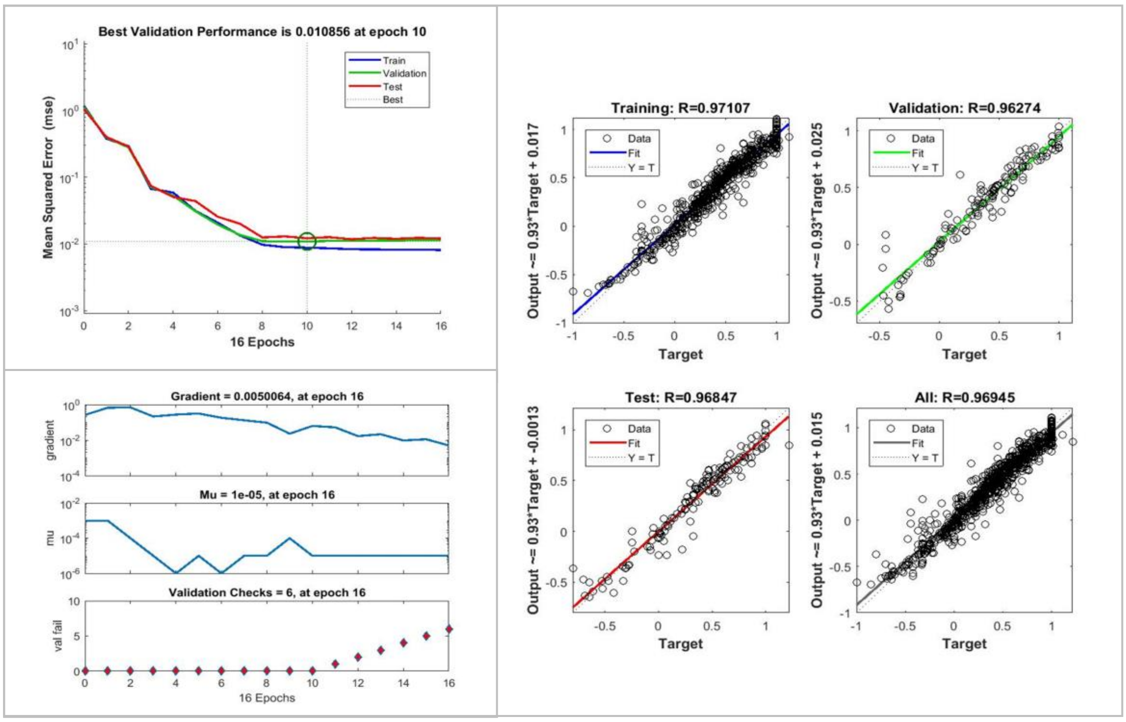


Figure 5.13(b): ANN3-5-2 (mu 0.001:0.1)

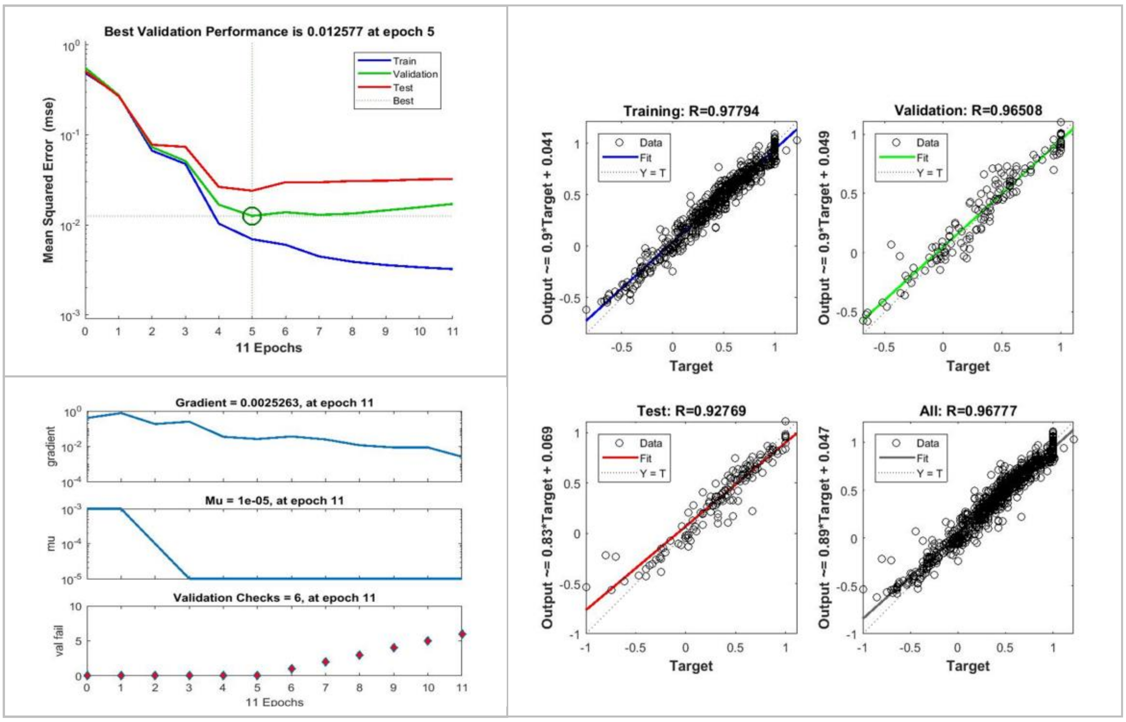


Figure 5.13(c): ANN3-5-3 (mu 0.01:0.15)

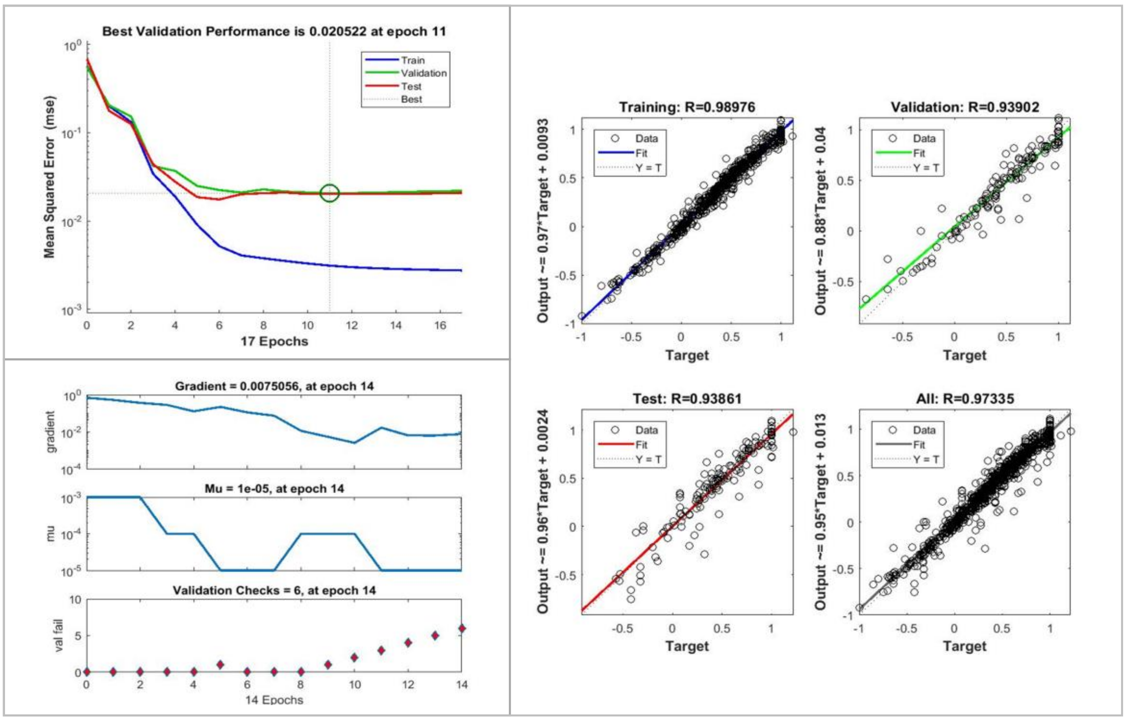


Figure 5.13(d): ANN3-5-4 (mu 0.01:0.25)

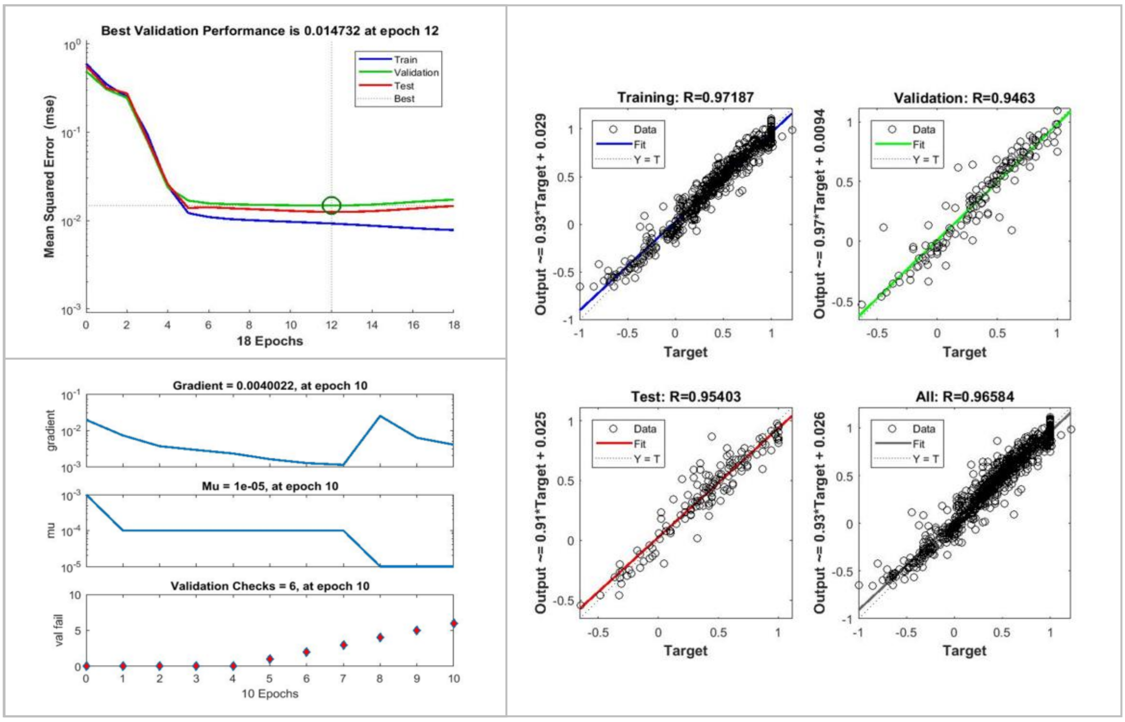


Figure 5.13(e): ANN3-5-5 (mu 0.1:0.02)

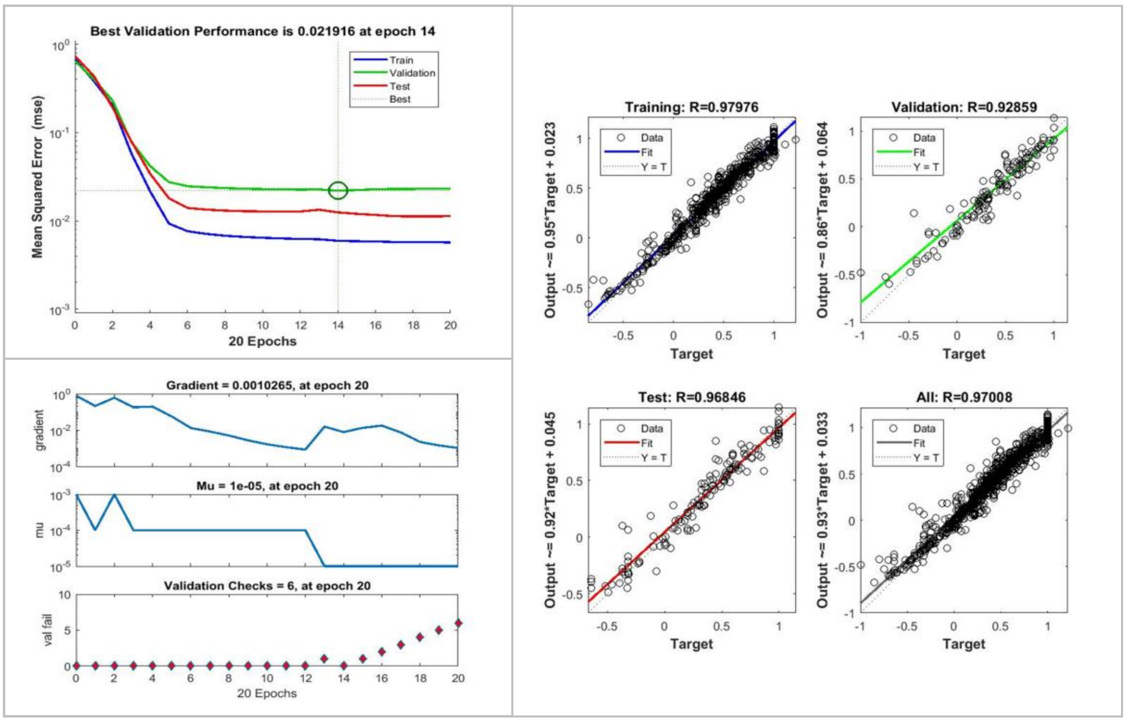


Figure 5.13(f): ANN3-5-6 (mu 0.01:0.5)

Table 5.5: Results of developing mu values at 2nd stage

Model	*Mu: mu_dc*	MSE	R on training	R on validation	R on test	All R	Gradient
ANN3-5-1	0.001:0.01	0.0143	0.9752	0.9604	0.9537	0.9690	0.0012
ANN3-5-2	0.001:0.1	0.0108	0.9711	0.9627	0.9684	0.9694	0.0050
ANN3-5-3	0.01:0.15	0.0126	0.9779	0.9651	0.9277	0.9677	0.0025
ANN3-5-4	0.01:0.25	0.0205	0.9897	0.9390	0.9386	0.9733	0.0070
ANN3-5-5	0.1:0.02	0.0147	0.9719	0.9463	0.9540	0.9658	0.0040
ANN3-5-6	0.01:0.5	0.0219	0.9797	0.9286	0.9685	0.9701	0.0010

At this stage, R and MSE values showed improvement in all models with modified mu values, but the significant value was 0.001:0.1 in ANN3-5-2, where R in all phases (training, validation and testing) was 0.9694. (Table 5.5). Although this was not the highest value of R, ANN 3-5-2 had the lowest MSE value of 0.0108 and was therefore selected to be used at the next stage to develop the efficiency of the model.

The third stage was to develop the gradient value of ANN 3-5-2 in the range of 1-e^3 to 1-e^{10} to refine the model's curve and reduce defragment values while optimising the values of R and MSE. Different values of gradient were tried to determine which ones would significantly improve model efficiency. The results, which identified the best performing version to be used as the final model, are presented in Figure 5.14(a-d), where each heading gives the gradient value of the model under test.

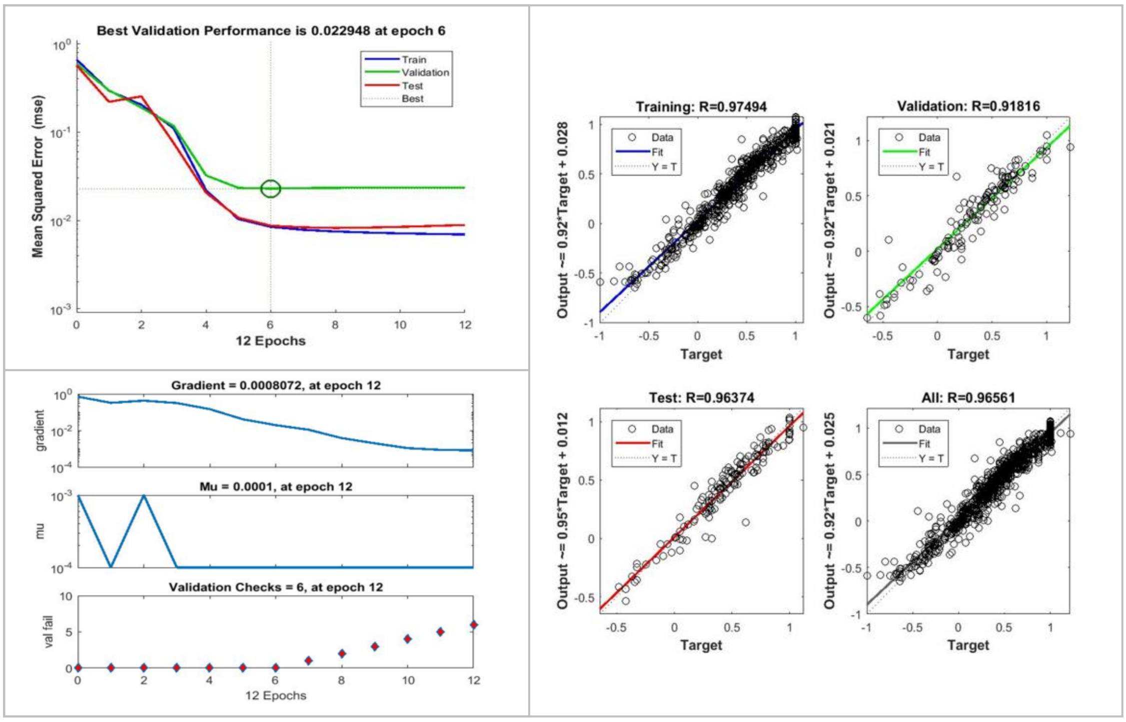


Figure 5.14(a): ANN3-5-2-1 (gradient value 1-e[3])

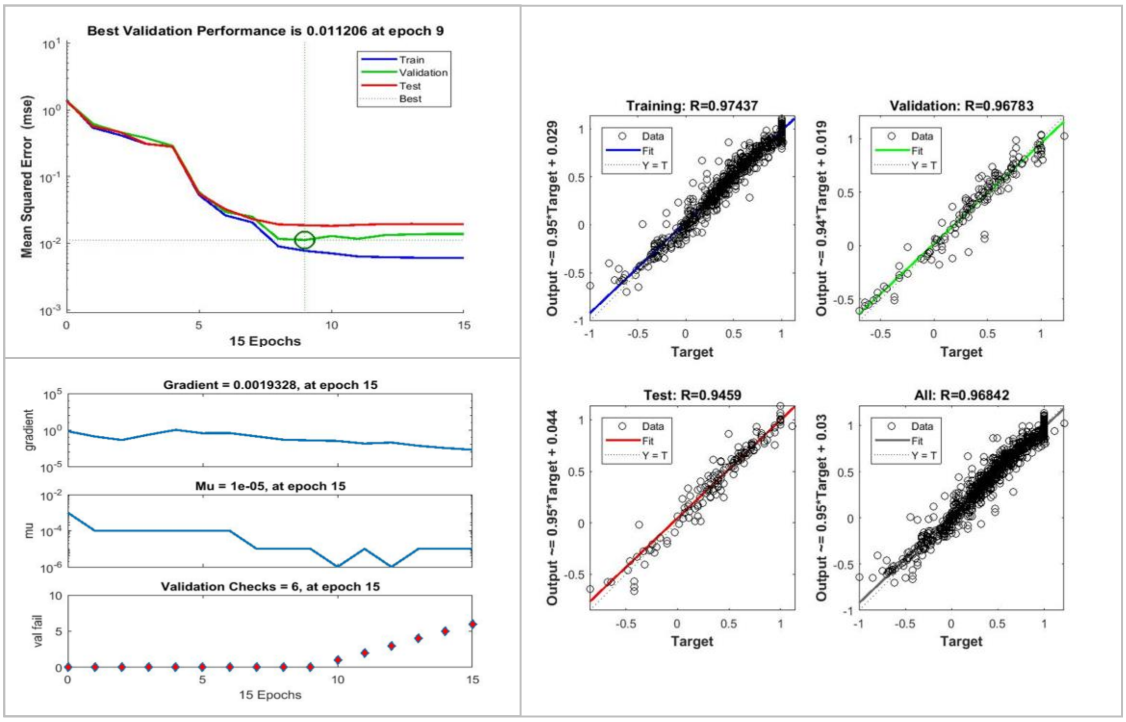


Figure 5.14(b): ANN3-5-2-2 (gradient value 1-e[6])

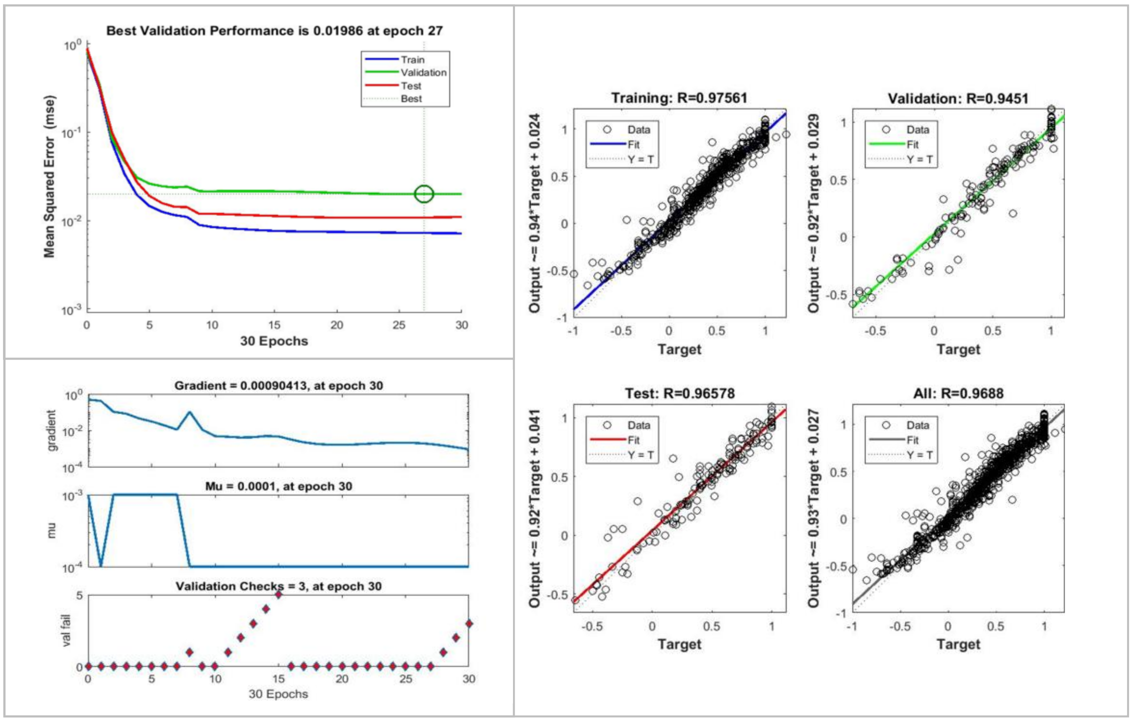


Figure 5.14(c): ANN3-5-2-3 (gradient value 1-e[9])

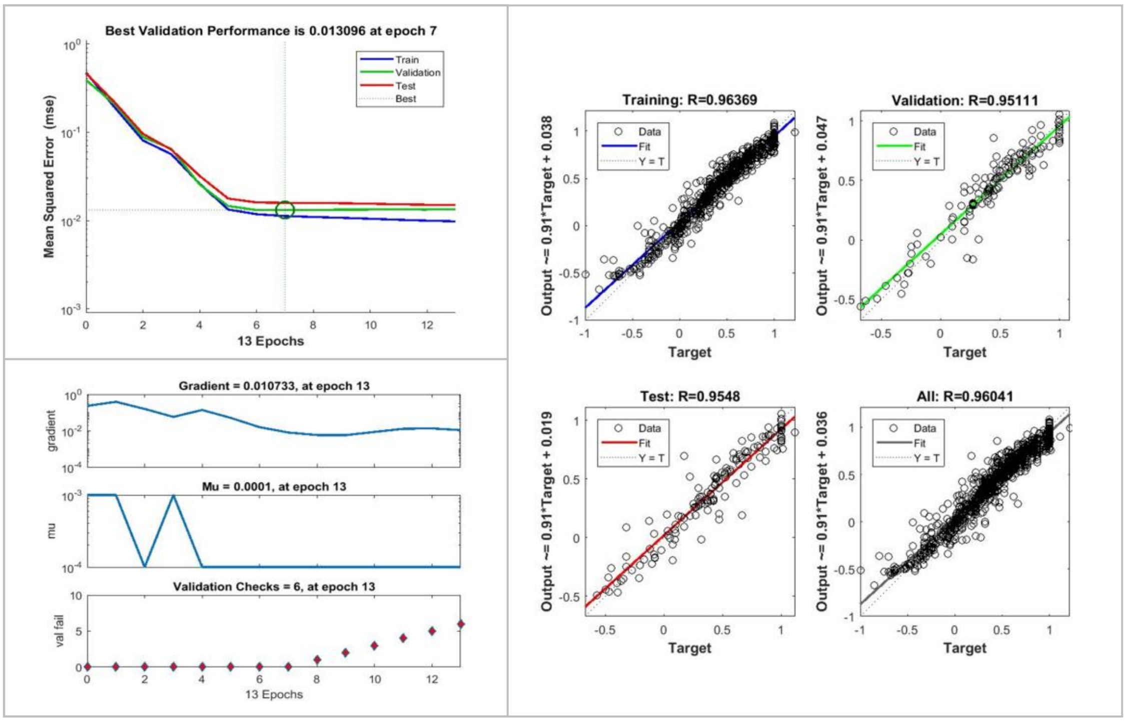


Figure 5.14(d): ANN3-5-2-4 (gradient value 1-e[10])

Table 5.6 depicts the results of the statistical standards MSE, R and min_ gradient, which were used to assess the degree of agreement among predicted and observed IEQ values of trainLM with different numbers of layers and neurons during the modelling stages. The gradient stage was implemented to develop the ANN 3-5-2 model, which showed some improvement over the gradient curve model, although in four models the MSE value of 0.0108 increased expect ANN 3-5-2-3 and the all R value decreased from 0.9694 at the previous stage. In contrast, the earlier gradient value of 0.0050 was reduced in all models except ANN3-5-2-5 when min_ gradient was altered.

Table 5.6: *Results of 3rd stage – min_gradient*

Model	*Min_ gradient*	MSE	R on training	R on validation	R on test	All R	Gradient
ANN3-5-2-1	$1\text{-}e^{3}$	0.0229	0.9750	0.9181	0.9637	0.9656	0.0008
ANN3-5-2-2	$1\text{-}e^{6}$	0.0112	0.9744	0.9678	0.9459	0.9684	0.0019
ANN3-5-2-3	$1\text{-}e^{7}$	0.0082	0.9756	0.9720	0.9319	0.9681	0.0017
ANN3-5-2-4	$1\text{-}e^{9}$	0.0199	0.9756	0.9451	0.9658	0.9688	0.0009
ANN3-5-2-5	$1\text{-}e^{10}$	0.0131	0.9637	0.9511	0.9548	0.9604	0.0107

The table shows that ANN3-5-2-1, when min_ gradient was $1\text{-}e^{3}$, had the highest value of MSE with the best gradient value of 0.0008, but the results displayed in Figure 5.15 determined that the best model, with all R at 0.9681 and MSE at 0.0082, was ANN3-5-2-3, which was therefore selected as the final model to be used to generate new data.

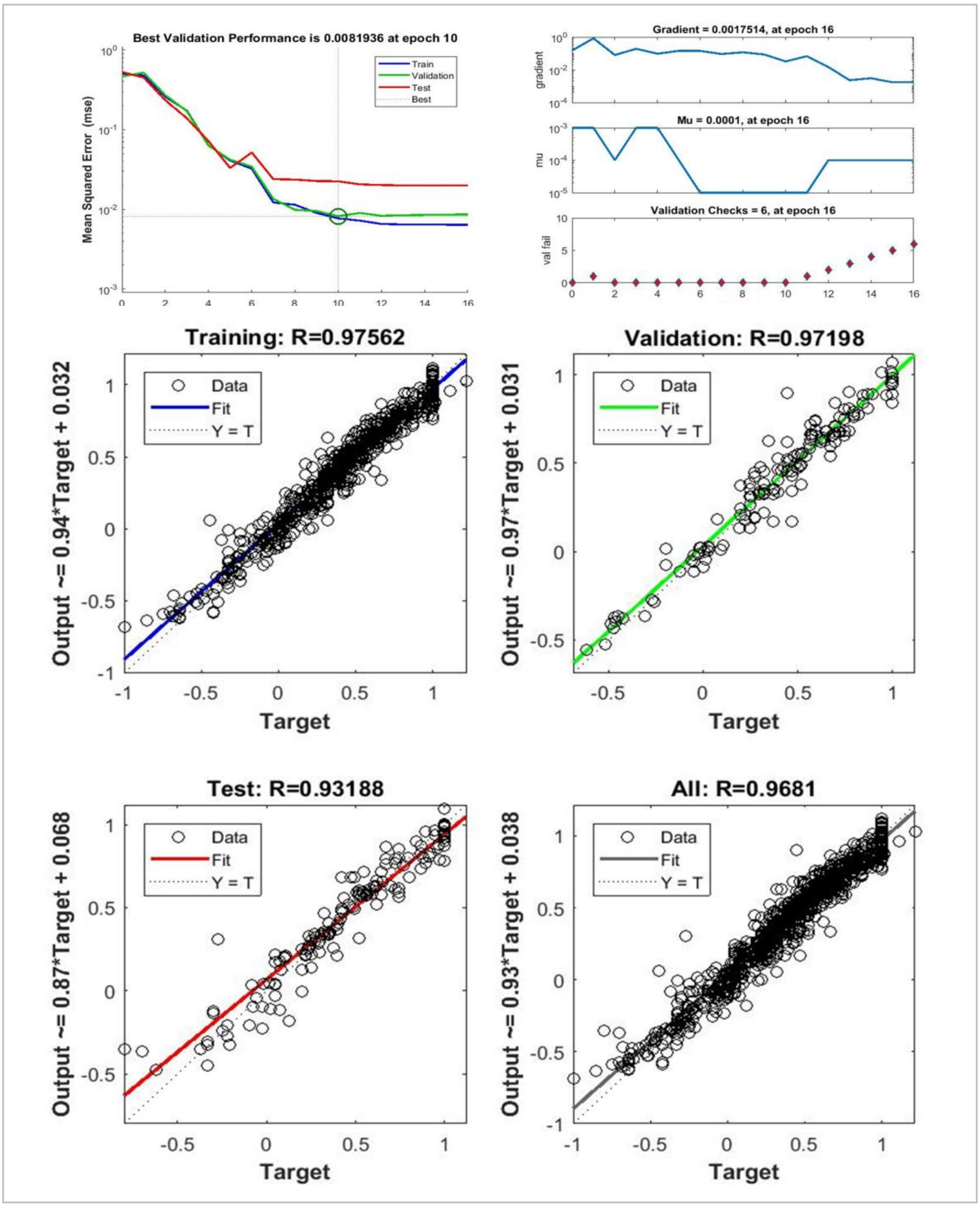


Figure 5.15: Final ANN model

5.8. Simulating Data in the ANN Model

The importance of neural networks is that they can be generalized to other data, from which valid recommendations can be made for future studies. The ability of an ANN to create new data from mean values and standard deviations when skewness of data distribution is almost normalized can be used to test the efficiency of the ANN model for this new data and evaluate its results, using traditional statistical methods. Five hundred new data points were generated via this model using the normrnd function of MATLAB, then the SPSS package was implemented to test the original data and the input data newly generated by the ANN model, thus evaluating its efficiency.

The parameters of evaluation were R-squared, the p-value, the t-statistic and standard error. R^2 is the proportion of the variance between the observed and predicted values of the dependent variable explained by variation in the value of the independent variable. The highest possible value of 1 depicts that the model explains all of the variability of the response data around its mean. The p-value is the level of marginal significance within a statistical hypothesis test demonstrating the probability of the occurrence of a given event.

The p-value is used as an alternative to rejection points to determine the lowest level of significance at which the null hypothesis would be rejected. A low p-value (typically ≤ 0.05) displays strong evidence against the null hypothesis, so it is rejected, whereas a large p-value (> 0.05) specifies weak evidence against the null hypothesis, which is not rejected.

The t-value measures the size of the difference relative to the variation in a sample of data. The regression is based on a large sample and observations, so a t-statistic greater than 2 (or less than -2) indicates that the coefficient is significant with 95% confidence. Finally, standard error is a measure of the statistical accuracy of an estimate, equal to the standard deviation of the theoretical distribution of the sample.

Table 5.8 shows that the values of the data generated by the ANN were close to the original data; the small differences can be explained by the non-normal distribution of the dataset. Statistically, the results of these tests indicate a significant correlation between the original and new data values, as $p < 0.01$ and the lowest value of R^2 was 0.924 on the wellbeing data.

Table 5.7: *SPSS comparison of original and generated data*

	Original data			Generated data		
	Comfort	Wellbeing	Performance	Comfort	Wellbeing	Performance
Adjusted R^2	0.967	0.972	0.970	0.950	0.924	0.932
p-value	0.000	0.001	0.000	0.002	0.004	0.001
t-statistic	3.869	-3.264	-3.774	3.156	-2.921	3.369
Standard error	0.002	0.002	0.002	0.005	0.006	0.005

5.9. Classification of IEQ Parameters

A classification scheme is used to organize individual objects into classes or categories, based on similarity of properties or characteristics among the objects in a given class. In linguistics, “the subordinate concept is called a hyponym of its superordinate” (IEC 61672-1., 2002).

It is important to evaluate IEQ performance at a whole-building level in order to ensure high IEQ and the adoption of measures to achieve high quality in design regulations (Wong et al., 2008). According to ASHRAE (2013), the term ‘quality of indoor environment’ refers to the perceived experience of the indoor environment that covers aspects of the design, analysis and operation of energy efficient, healthy and comfortable buildings, as well as fields of specialization including architecture, HVAC design, thermal comfort, indoor air quality, lighting, acoustics and control systems. These elements are considered indicators of building performance-rating tools that emphasize the importance of IEQ throughout the design, construction and operation of buildings.

The percentage weights of indicators were used to determine the values of IEQ parameters from objective and subjective surveys, as well as the extent to which they exceeded acceptable values (Lai et al., 2009). Heinzerling et al. (2013) state that the purpose of an IEQ tool is to classify the data contained in objective and subjective measurements into a rating or score. Toderașc and Iordache (2016) note that “it is important to score IEQ because it gives a good indicator of building performance, which affects not only the comfort, health and performance level of the occupants but also the operating costs of the building. The accuracy, relevance and applicability of scoring systems depend on the quality of the objective and subjective assessment data that have been collected". Therefore, several studies have attempted to correlate subjective and objective measures, combining objective measurements of each parameter and overall IEQ to predict occupants' comfort for each IEQ factor (REHVA, 2011).

In this study, the objective IEQ measurements for each factor were divided equally into five indexes, based on maximum and minimum values, then participants' subjective answers were matched with the physical measurements in order to classify the IEQ categories accurately. For example, lighting data were classified in five ranges of 60 lux each, so that index1 and index2 represented values of 351-410 lux and 411-470 lux respectively and so on for the other indexes. All other parameters were classified similarly and these IEQ categories were interpreted as equivalent to those of the colour scheme provided in EN15251-2007 on a five-point Likert scale: 1 = very uncomfortable (red), 2 = uncomfortable (orange), 3 = neutral (yellow), 4 = comfortable (green), 5 = very comfortable (purple).

5.9.1 Weighting scheme for IEQ parameters of comfort

A building is successful if it meets its users' needs, so a measurement of occupant comfort with IEQ is an essential part of assessing building performance, identifying valuable features and highlighting the main variables that affect the occupants' comfort (Zalejska and Willhelmsson, 2013). Therefore, to determine the IEQ score it is necessary to collect data to provide a total image of how the space is performing. These evaluations were made in the present study from objective physical measurements of indoor environmental parameters and from occupants' subjective survey responses (Heinzerling et al., 2013).

A comparison was made between the subjective survey assessments and the quantitative measures in order to determine whether the survey provided a true reflection of the dominant comfort condition in the classrooms. The results indicate that 95% of survey data on comfort evaluation matched the corresponding measurements of IEQ factors. Figure 5.16 illustrates these matches for all six IEQ comfort parameters. For instance, light quality and air quality values were close to each other in all categories. However, the values for thermal comfort, comprising temperature, humidity and ventilation flow rate, show that around half of respondents reported being comfortable or very comfortable, whereas only a quarter gave responses in these two categories for acoustic comfort, corresponding to sound levels below 53 dB. Conversely, the highest percentage of 'very uncomfortable' responses was 13% for sound level above 62.2 dB, as against 5% for very uncomfortable thermal conditions, i.e. temperature < 22 °C, humidity > 70% and ventilation flow rate < 0.20 m/s. As to neutral conditions, these were in the range of 19-36% on all IEQ parameters. Overall, the highest proportion of perceived comfort was in temperature, at 58%, while the highest percentage of discomfort was 44% for acoustic quality.

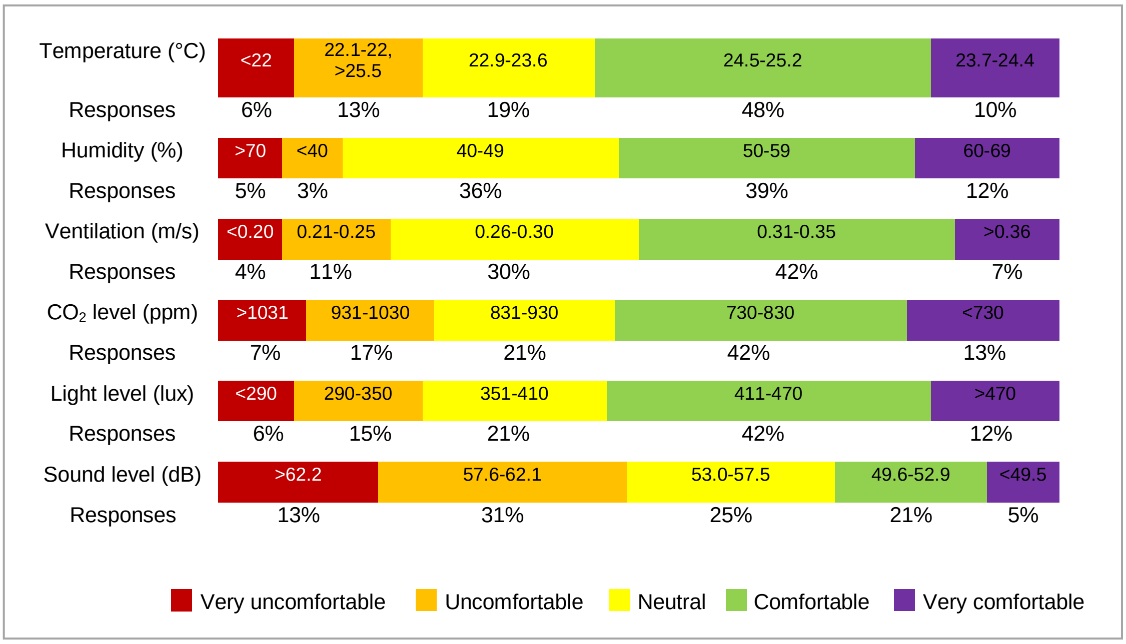


Figure 5.16: Comparison of IEQ assessment of comfort

5.9.2 Weighting scheme for IEQ parameters of wellbeing

A combination of physical IEQ measurements and survey provides a more detailed overview of environmental quality in classrooms and of teachers' wellbeing, although when IEQ standards are applied, occupants are often not comfortable with indoor conditions. Several studies have implemented this method of investigating the relationship between physical measurements and the subjective responses of participants (Valeria et al., 2015).

In this study, comparing teachers' survey responses on their wellbeing with the corresponding objective measurements of IEQ indicated that 92% of their answers fitted with those measurements. Figure 5.17 illustrates teachers' perceptions of IEQ factors. On thermal conditions, 55% gave positive responses, corresponding to temperature in the range of 24.5-25.2 °C, humidity of 50-59% and ventilation rate of 0.31-0.35 m/s, while 5% responded very negatively, equivalent to temperatures below 22 °C, humidity above 70% and air flow less than 0.20 m/s. On air quality, 54% recorded responses of positive wellbeing, corresponding to CO_2 levels of 730-830 ppm, whereas only 3% perceived their wellbeing very negatively, equivalent to CO_2 > 1030 ppm.

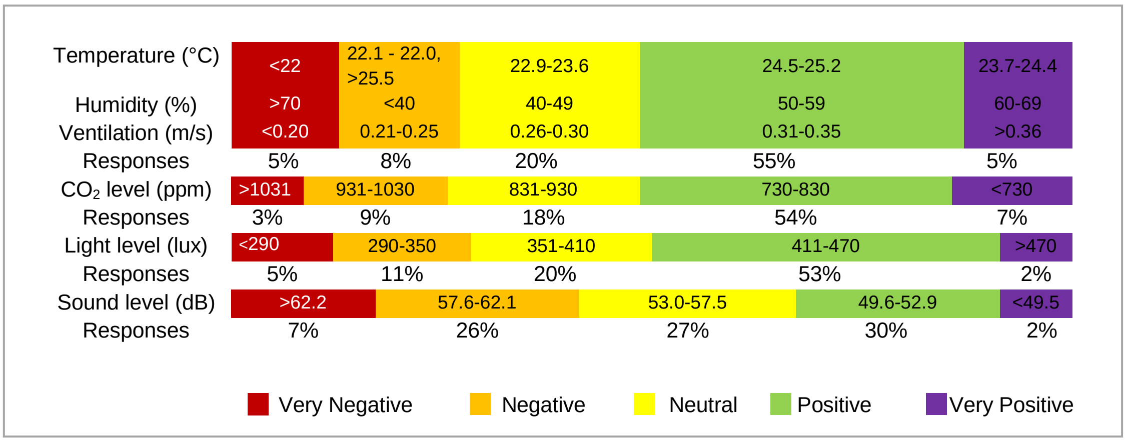


Figure 5.17: Comparison of IEQ assessment of wellbeing

Light quality was perceived to affect the wellbeing of 53% of participants positively, corresponding to a light level between 411and 470 lux, while only 5% reported very negative wellbeing (< 290 lux). The extent of the effect of acoustic quality on wellbeing is unclear, because the negative, neutral and positive responses were broadly similar, with a total of 33% giving negative or very negative responses and 32% responding positively or very positively.

Overall, there was a tendency to perceive a positive effect of IEQ on wellbeing, the highest proportion of positive and very positive responses being 61% for air quality, while the lowest percentage was for acoustic quality.

5.9.3 Weighting scheme for IEQ parameters of performance

Occupants' comfort in buildings is associated with the quality of the indoor environment and building elements, which directly affects their level of performance. Occupants are the best source of information on the performance of the building that the design community can obtain. It is essential to evaluate the quality of buildings in terms of the effects on comfort, productivity and health (Zagreus et al., 2004). This study found that 93% of responses regarding participants' perceptions of performance based on IEQ criteria fitted the quality of classrooms as measured objectively. Figure 5.18 shows that the highest positive effect on performance level was 57% for air quality when the CO_2 level was measured between 730 and 830 ppm, followed by thermal comfort at 55% when temperature ranged from 24.5 to 25.2 °C, humidity from 50 to 59% and air flow from 0.31 to 0.35 m/s. More than half of respondents perceived the light level positively or very positively when it was above 410 lux and about a third felt that sound level had a positive effect on performance below 53 dB. On the other hand, only 3% perceived a very negative effect of thermal comfort when temperature was recorded below 22 °C, humidity above 70% and air flow less than 0.20 m/s, whereas the largest very negative response concerned acoustic quality when sound level was above 62.2 dB. Neutral responses on all of these parameters were in the moderate range between 18 and 29%. Overall, thermal comfort was found to have the highest rated positive or very positive effect on performance, at 63%, while acoustic quality had the strongest combined negative response at 33%.

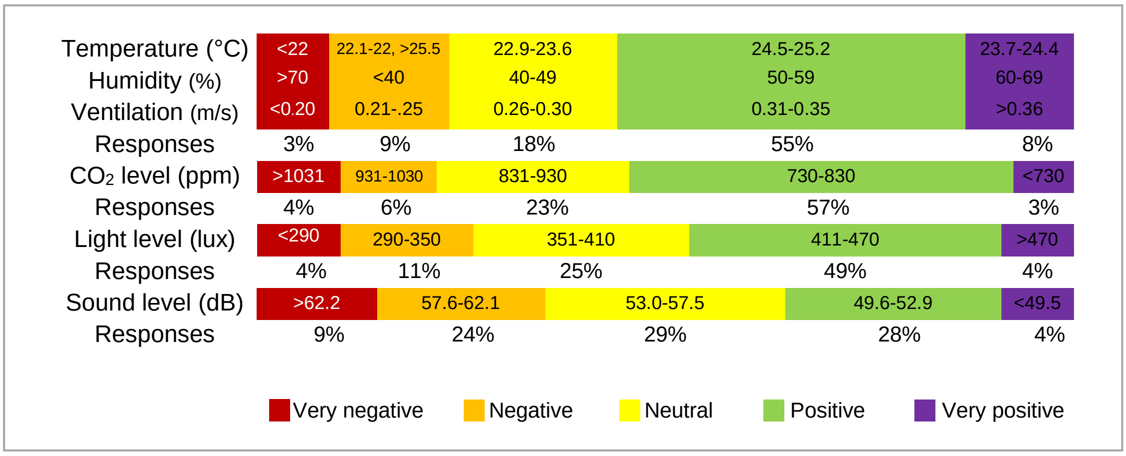


Figure 5.18: Comparison of IEQ assessment of performance

5.10. Relationships of IEQ parameters with performance

The quality of the environment inside educational buildings is of particular concern because there are usually many users, i.e. students and teachers, in a limited area. Poor IEQ is not only unhealthy for occupants (Katafygiotou and Serghides, 2014), but will also contribute negatively to the performance of teachers and the quality of students' learning. Lee et al. (2012) elicited subjective assessments and took objective measurements in university teaching rooms, concluding that there was an association between learning performance and IEQ. The ANN model developed for the present study indicates a strong relationship between IEQ parameters and performance generally; the following subsections offer a detailed analysis of this association, considering objective measurements and subjective assessments in turn.

5.10.1 Relationships of objective measurements of IEQ parameters with performance

In order to assess the condition of a building, it is essential to gather both objective measurements of IEQ parameters and the subjective evaluations of users. This study measured temperature, humidity, ventilation flow rate, CO_2 concentration and levels of light and sound. While these physical measurements of classrooms were being recorded, the teachers were asked to evaluate their indoor environment. A number of equations were tested statistically and the polynomial function of three degrees was found to be a reliable formula when used to determine the R^2 coefficient. The function is given by the following formula, in which a is nonzero:

$$f(x) = ax^3 + bx^2 + cx + d \qquad (10)$$

The R^2 value applied to correlate the relationship between IEQ and performance depends on the participants' responses.

Calculating the quantitative effect on performance from the measurement record and survey data reflects the users' reality and the building's performance. The performance level was found to vary as the recorded data varied and each of the resulting slopes in the relationship of performance with IEQ parameters was associated with actual recorded values for each specific assessment. All data points in the following six graphs (Figures 5.19-5.24) were derived by plotting performance on the vertical axis, on a scale of 1 (lowest performance) to 5 (highest performance), against the assessment of an IEQ parameter on the horizontal axis.

5.10.1.1 Temperature and performance

Temperature is the parameter having the greatest effect on thermal comfort. ASHRAE 55, EN15251 recommends an optimal temperature between 23 °C and 26 °C to achieve a comfortable condition for users. The study found that the temperature measurements in classrooms varied between 21.5 °C and 26.5 °C. These variations of temperature were due to the running time of the HAVC system, which was shut down at the end of each academic day and remained off during the night, before being turned on again early each morning.

The temperature in many classrooms was found to be at its highest when the first measurement of the day was taken, the average outside temperature being higher than 30 °C. Consequently, many teachers reported feeling uncomfortable when observed during data recording. The graph in Figure 5.19 shows that performance level increased gradually with temperature up to 24.5 °C, then declined sharply with a further rise.

When the temperature was recorded as close to 21 °C in the classrooms, some students were observed to be wearing coats in order to maintain their thermal comfort. They did not have the alternative of controlling the room temperature, because the HVAC thermostat was not accessible to them.

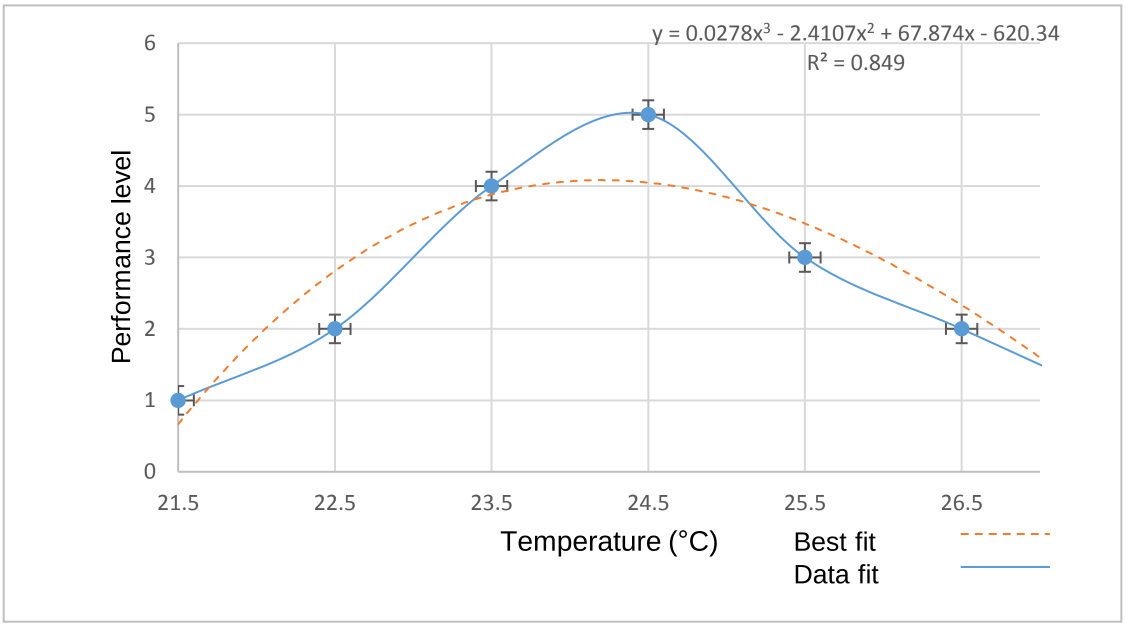


Figure 5.19: The relationship of temperature with performance

The R^2 value of 0.849 is interpreted as denoting a good relationship between temperature and performance, where an increase in temperature above 23.5 °C is correlated with a statistically significant improvement in performance and an increase above 25.5 °C is associated with a significant decrease in performance. In other words, the range of temperature between 23 °C and 25 °C is considered optimum for performance. This result also delivers a good prediction of how performance level varies with temperature between 21.0 °C and 26.5 °C.

5.10.1.2 Humidity level and performance

The second parameter contributing to thermal comfort is relative humidity, which should be in the range of 30-70% according to the recommendations of ASHRAE 55, EN 15251 and ISO 9902. The present study measured relative humidity levels to determine their effect on teacher performance and found that they varied between a minimum of 37% and a maximum of 75%. Figure 5.20 charts the relationship of relative humidity to performance, showing that it improved with increasing humidity up to 65%, which is considered the optimal level for maximum performance, then fell when humidity rose further. Statistically, the R^2

value was 0.9643, indicating a strong relationship between the independent variable of relative humidity and the dependent variable of performance.

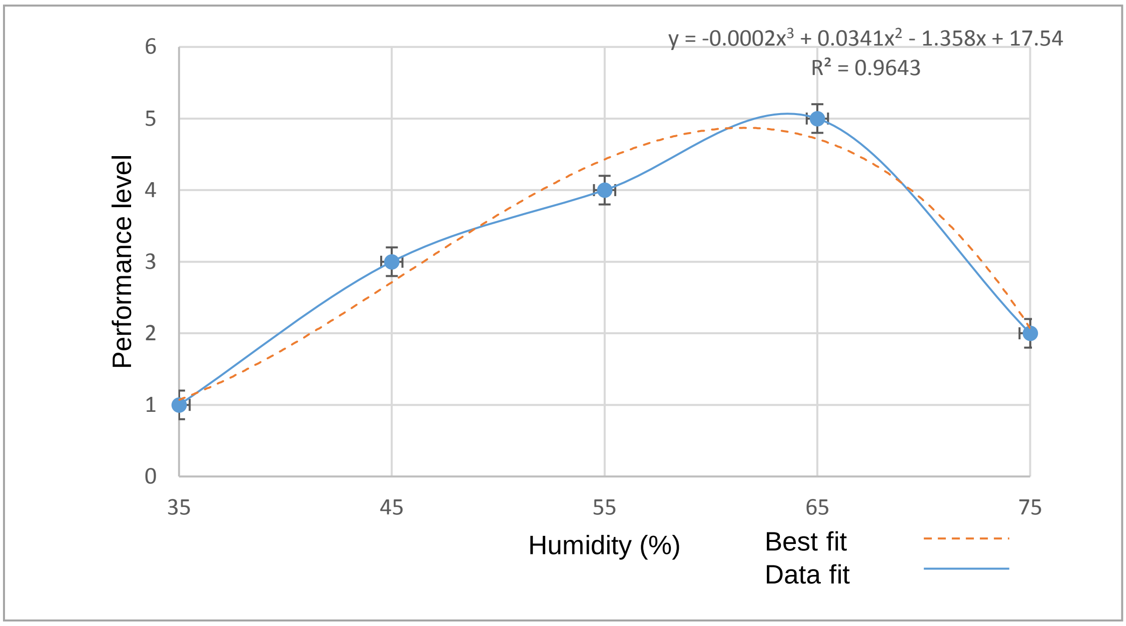


Figure 5.20: The relationship of humidity level with performance

5.10.1.3 Ventilation rate and performance

Ventilation, the third contributor to thermal comfort, also provides protection against moisture, odours, chemical compounds, particles, allergens and microorganisms. However, to ensure good ventilation, the HVAC system must work properly, which requires attention to be paid to its design and operation. Failure to clean filters and poor maintenance may cause annoyance and symptoms of illness among occupants. The study found that increasing the ventilation flow rate in classrooms improved teaching performance and student achievement. The lowest mechanical ventilation rate was measured at 0.20 m/s and the highest at 0.40 m/s. Figure 5.21 charts the relationship between ventilation flow rate and performance, indicating a significant correlation with an R^2 value of 0.9643, showing that increasing the flow rate was associated with improved performance. However, when the rate exceeded 0.40 m/s, performance declined slightly, due to the increased noise level of the HVAC system when operated at that rate.

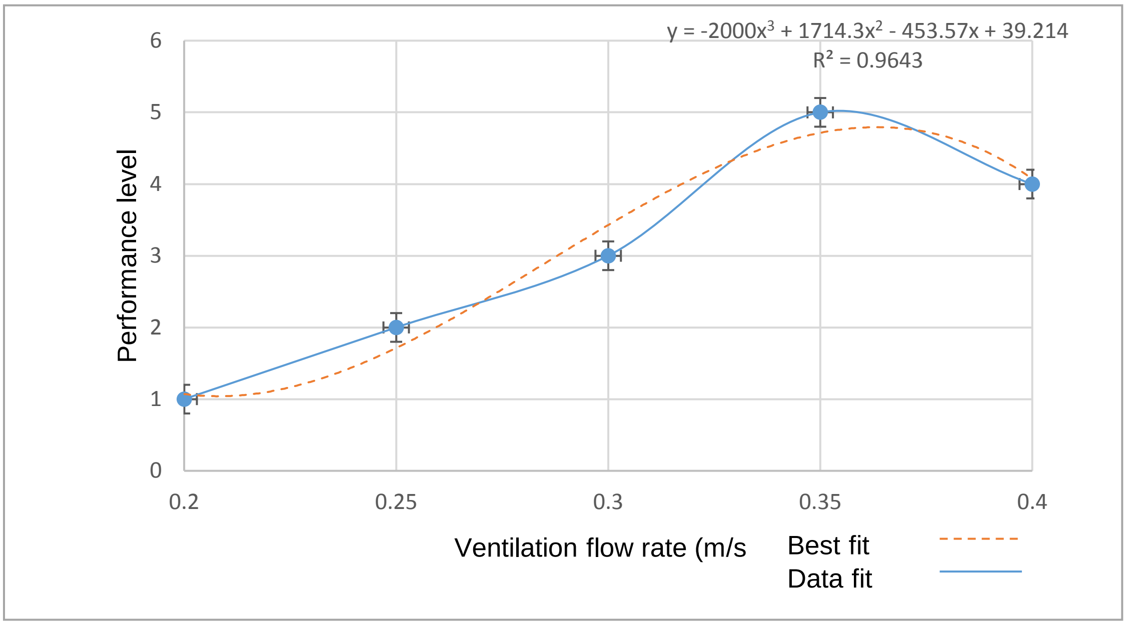


Figure 5.21: The relationship of ventilation rate with performance

5.10.1.4 CO_2 concentration and performance

Carbon dioxide concentration is considered the main indicator of indoor air quality. In the majority of international standards, CO_2 is used as a key indicator of ventilation performance, as its concentration tends to fall with increasing ventilation flow rate. The comparative analysis (Figure 5.22) found a significant association between performance level and CO_2 concentration, R^2 = 0.9753. Performance was at a maximum when the air contained less than 650 ppm of CO_2 and fell gradually up to 1050 ppm. No difference in performance was detected when CO_2 concentration was between 850 and 950 ppm, where a moderate level of performance was maintained.

These results may be correlated with ventilation flow rate and air quality, given the inverse relation between ventilation and CO_2 noted above. A smell of smoke was evident in several of the ground floor classrooms included in the study, especially those close to car parks and toilets.

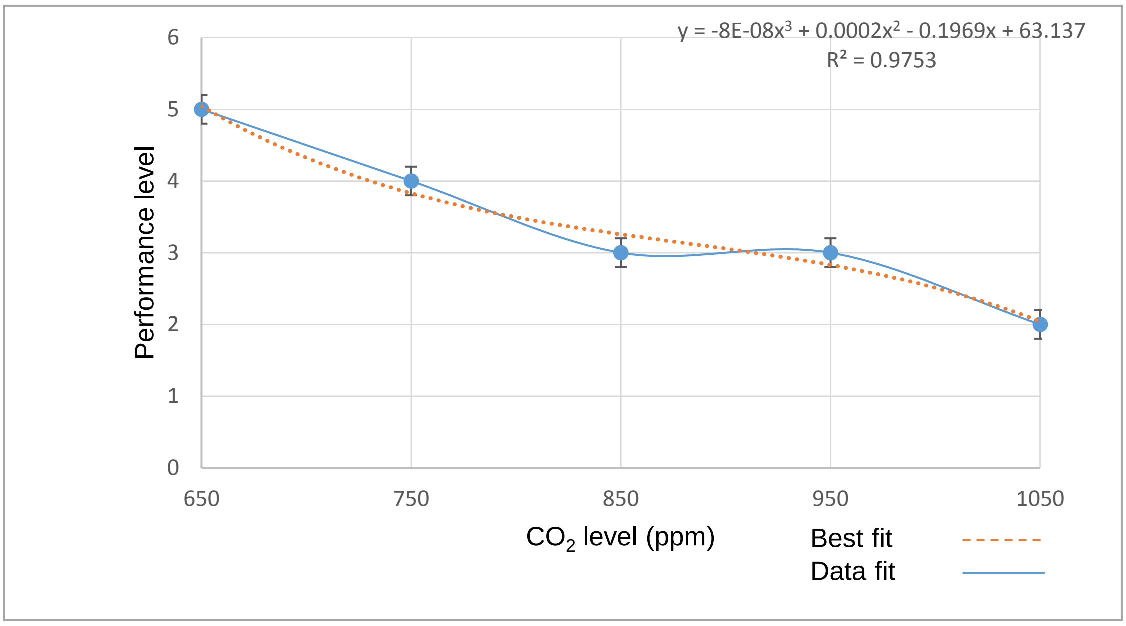


Figure 5.22: The relationship of CO_2 level with performance

5.10.1.5 Lighting quality and performance

Lighting is a fundamental element of building design, since well designed lighting will provide appropriate visual quality for all building users. Varying the light level will affect visual performance and when users can see the task clearly they will perform better. The data plotted in Figure 5.23 show that as light level increased performance improved. Statistically, R^2 was significant at 0.9712, indicating a strong correlation between visual quality and performance. Illuminance was measured as varying between 244 lux and 540 lux. The graph depicts a gradual improvement in performance from 250 lux to 500 lux, with a constant and the highest level of performance between 400 and 450 lux. This analysis shows that lighting quality is a source of visual comfort with clear importance in all tasks. Nevertheless, some tasks do not need much light in order to be performed well visually. Moreover, it was noticed that light transmitted and reflected by window glass and bright surfaces such as brightly coloured ceramic floor tiles, especially in classrooms with desks arranged in a U shape, caused glare when light intensity was high, leading the occupants to draw the curtains to avoid such glare.

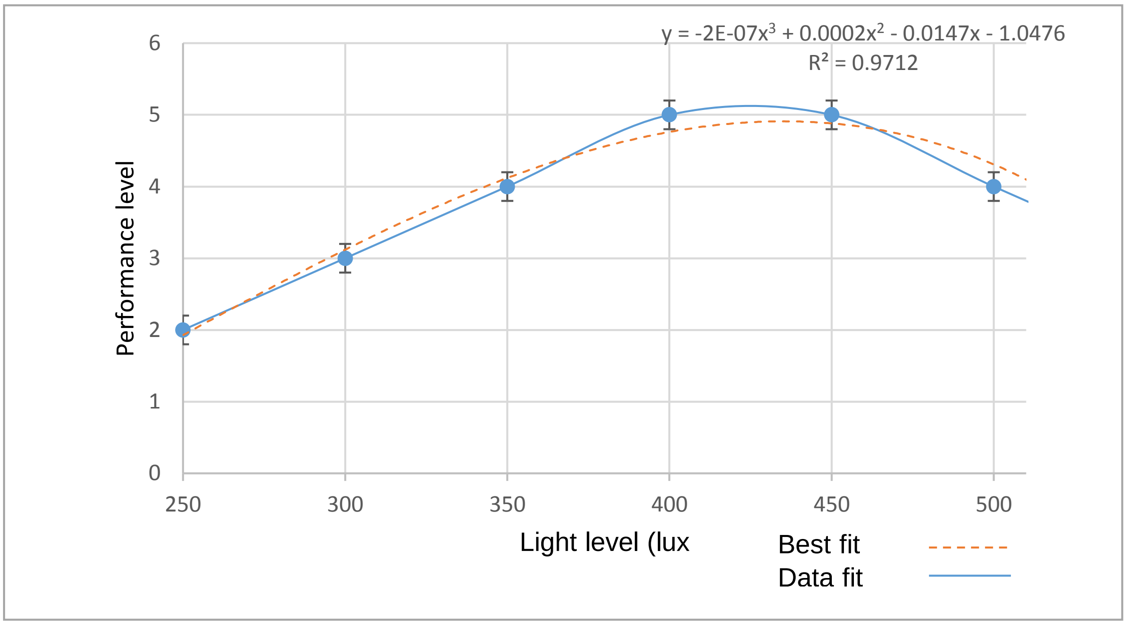


Figure 5.23: The relationship of light quality with performance

5.10.1.6 Acoustic quality and performance

The acoustic quality of classrooms is the IEQ factor that affects educational outcome most strongly, because speech communication is critical to the learning process and noise may disturb this activity and reduce the ability of both teachers and students to concentrate on the lesson or lecture. Sources of noise can be categorized as external ones, such as traffic and other street sounds, versus internal sources, within the classroom itself and other parts of the building such as neighbouring classrooms, corridors and the HVAC system. Noise level was measured objectively as ranging from 44 dB to 77 dB. Figure 5.24 depicts the relationship between acoustic quality and performance, showing that performance was at its best when the noise level was below 50 dB, because quiet and comfortable spaces enhance the teaching process. The R^2 value indicates a significant association between these two variables. It is notable that performance declined when noise rose above 50 dB.

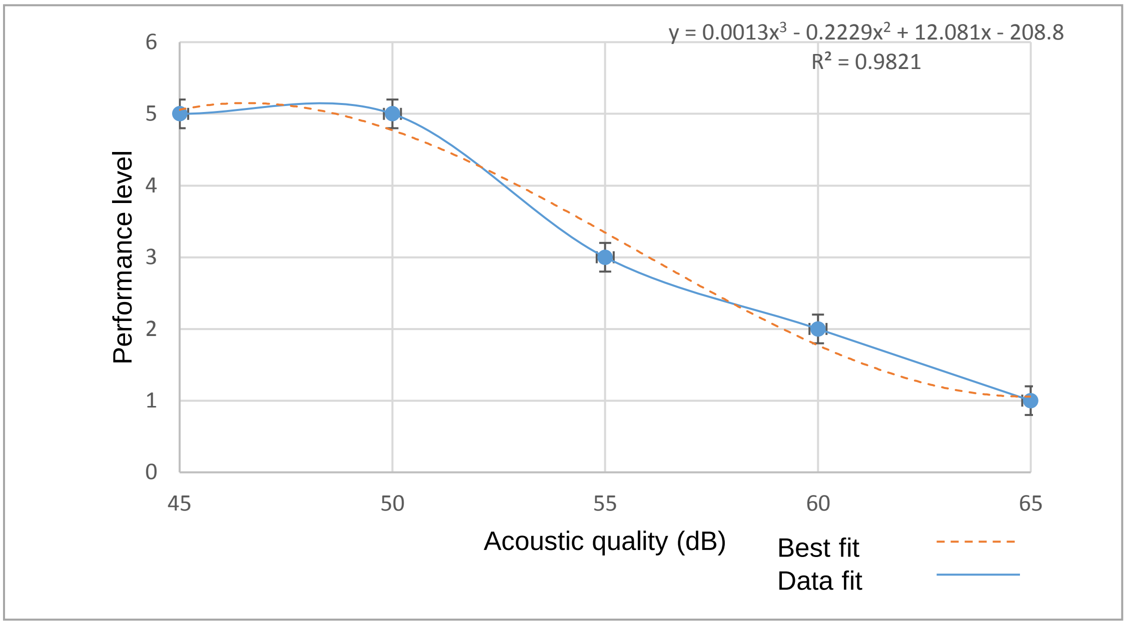


Figure 5.24: The relationship of acoustic quality with performance

5.10.2 Relationships of subjective assessments of IEQ parameters with performance

A survey was conducted to evaluate teacher's subjective assessments of performance and their relationships with aspects of the IEQ of their classrooms that were considered to affect learning outcomes. The survey strategy which was selected was based on the questionnaire survey method recommended by several standards such as EN ISO 10551, the Post-Occupancy Evaluations (POE) questionnaire model, the Center for the Built Environment (CBE) model and by the authors of various studies (Abbaszadeh et al., 2006; Fowler and Rauch, 2008; Lee and Guerin, 2009; Choi et al., 2014). The factors evaluated by subjective means only were classroom layout, view, look and feel, and amenities. A total of 321 observations via survey were used to evaluate the relationships of these factors with performance. R^2, root mean square error (RMSE) and mean absolute error (MAE) values were used to quantify these relationships. The four main linear regression models (stepwise, linear, interaction and robust regression, with fivefold cross-validation) were run at one time in MATLAB R2017a and the best values for these regression models were found to be R^2 = 0.983, RMSE = 0.01 and MAE = 0.02. The fivefold cross-validation, which was applied to avoid overfitting, involved partitioning the dataset into folds and estimating accuracy on each fold.

5.10.2.1 Layout and performance

The layout of a classroom is a physical characteristic that can be effectively manipulated to ensure high performance by both students and teachers. The classrooms in this study were all rectangular in shape, having an area of 72 m^2. There were on average 25 students in each class, allowing around 2.85 m^2 for each student. The students' chairs, which were portable, each with an adjustable desk attached, were placed in rows facing the teacher's table at the front of the room. Positive feelings about layout that may make people more comfortable in the learning environment might be associated with stronger student and teacher performance. This association was confirmed statistically in this study via linear regression, showing a strong correlation between layout and performance. Figure 5.25 illustrates the different regression models used in this analysis and shows that the best model was stepwise linear regression with the following values of statistical parameters: R^2 = 0.94, RMSE = 0.06 and MEA = 0.05.

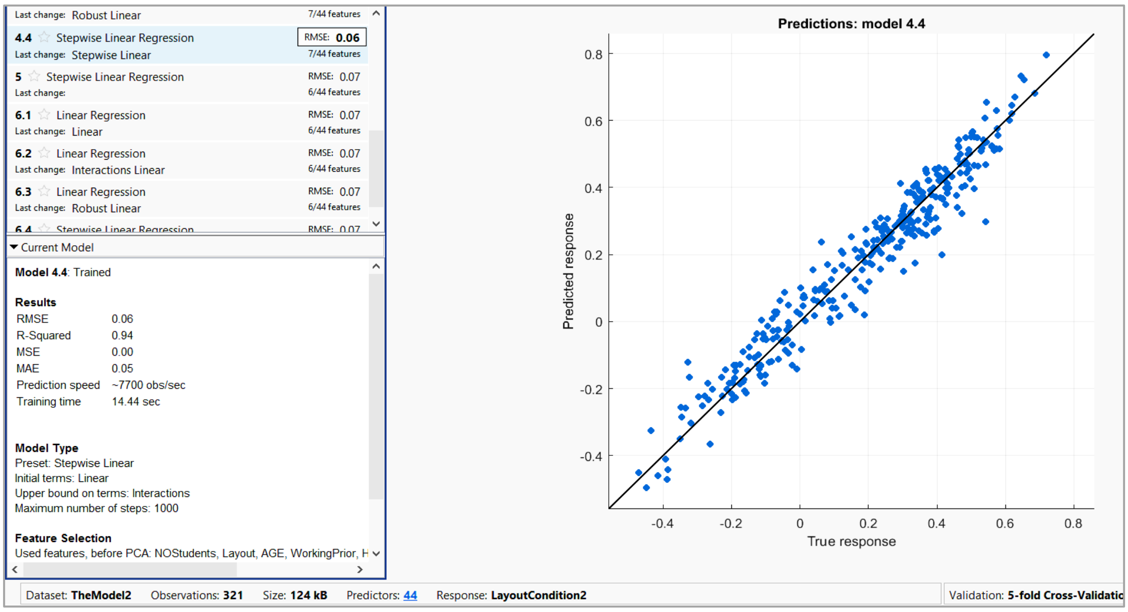


Figure 5.25: The relationship between layout and performance

5.10.2.2 View, biophilia and performance

The natural environment inside and around school facilities will influence the performance of users; for example, creating pleasing views has been found to have a positive effect on the comfort and performance of both teachers and students. Occupants of any building who have views of nature through the windows tend to have a higher level of happiness and wellbeing because they are connected visually with the natural environment, creating a positive mood which may reduce stress, anxiety and tension, thus improving their performance. The landscape surrounding the case study school consisted of mountains and valleys on three sides and new construction on the fourth side. The statistical analysis revealed a good relationship between view and performance, as depicted in Figure 5.26, where R^2 = 0.87, MSE = 0.11 and MAE = 0.09.

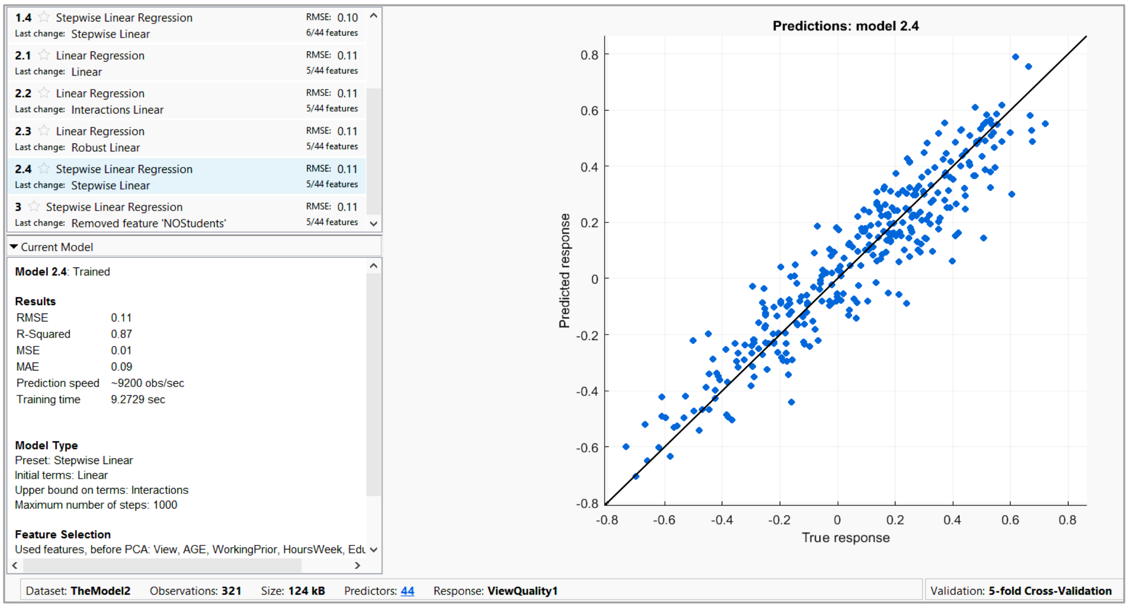


Figure 5.26: The relationship of view and biophilia with performance

5.10.2.3 Look, feel and performance

The look and feel of a workplace, including its colour scheme and décor, affect the perceived quality of the space, which is an important factor influencing the efficiency of people working in that environment. Each colour has different effects on the human body, reflected in the individual experiences of the building's users. People react differently to different colour schemes, depending on their culture, education, genetics and economic condition. Consequently, behaviour and performance are influenced but not determined by the look and feel of the workplace. This is a particularly complicated set of factors to evaluate, because responses and feedback will depend partly on respondents' psychological feelings and mood. Barrett et al. (2015) suggest employing experts to deliver a comprehensive judgement of look and feel. The present study found a statistically significant correlation between the look of classrooms and the performance of their occupants via linear regression: R^2, RMSE and MAE values were all within acceptable limits at 0.82, 0.09 and 0.07 respectively, as Figure 5.27 shows.

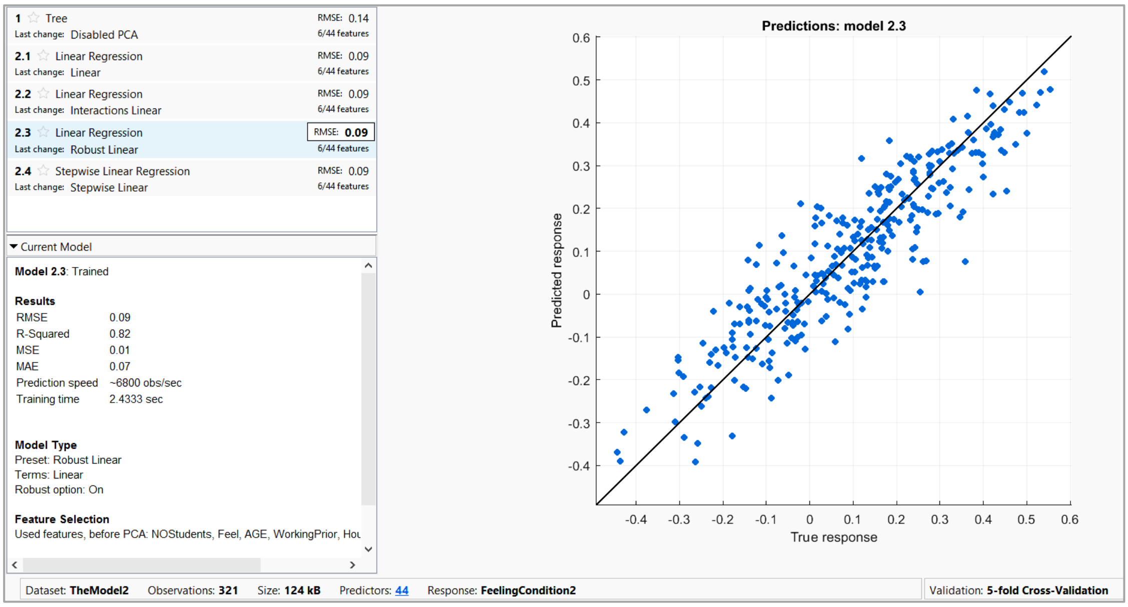


Figure 5.27: The relationship of look and feel with performance

5.10.2.4 Location, amenities and performance

It is essential to consider the location of a workplace when deciding between available sites. The accessibility of public infrastructure to the occupants is important because of the potential to reduce fuel use and journey time by locating premises close to public transport services, for example. The assessment of teacher performance in school should focus on physical conditions, including the availability of the amenities that are required to support learning. Functional comfort is defined in terms of the support afforded by amenities for users' performance of work-related tasks and activities. It was found that the condition of school facilities was positively correlated with teacher performance and student achievement. The regression analysis of the relationship of location and amenities with performance is addressed in Figure 5.28, which shows that the values of R^2, RMSE and MAE were all acceptable, at 0.72, 0.13 and 0.11 respectively. These values were not significantly correlated with the responses regarding the location and amenities of the case study school, because some of respondents felt uncomfortable about their journeys to and from the premises: the majority of respondents reported having to travel an average of approximately 25 km twice a day in rush-hour conditions, in the absence of public transportation. Teachers also evaluated the local amenities as not of sufficiently high quality to encourage good performance and complained about their poor maintenance.

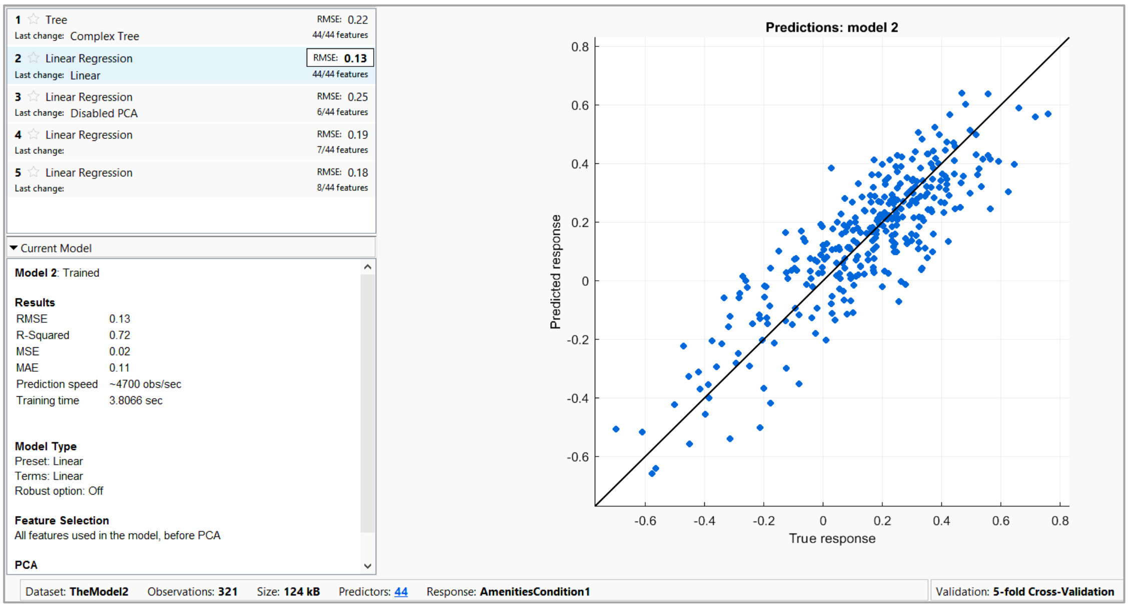


Figure 5.28: The relationship of location and amenities with performance

In summary, the application of artificial neural networks to the indoor physical environment can be used to quantify associations between environmental factors and teachers' comfort, wellbeing and performance that are difficult to compute by means of traditional statistical techniques (Santos et al. 2012).

There are several batches of neural networks with many different structures, all described in terms of the transfer functions utilized in the processing elements (neurons), using the training algorithms connected with mathematical formulae. The training of ANNs involves optimizing each element, such as by adjusting weights, functional parameters of the transfer functions and the topology. A multilayer perceptron network and backpropagation-learning algorithm were constructed; however, the most common topologies of ANNs are feed forward. The feed-forward topology links all of the neurons in the previous layer to all of those in the next layer, thus feeding the signals forward through the network.

The main difficulty in adopting an ANN is the selection of the most appropriate configuration of learning, training and transfer functions. The choice of proper transfer functions for each layer is crucial when building a neural network, as is deciding whether there are to be layers that have hybrid neurons with different combinations of transfer functions. The transfer function is implemented on the weighted sum of the neurons' inputs to create neural network models. The most widely utilized transfer functions are the hyperbolic tangent, sigmoid and Gaussian functions.

Training algorithms have a number of batch forms which are used to train a network. The three main types are gradient descent algorithms, conjugate gradient algorithms and quasi-Newton algorithms and these were tested to select the most suitable one for this research. They were created as a matter of practicality using the MATLAB software, which is considered a credible method of solving the complicated relationships between the input and output factors. The two standard statistical performance criteria, the correlation coefficient R and MSE, were calculated to evaluate the performance of the ANN algorithms, in order to select the most accurate and efficient algorithms.

The condition of a building is acceptable when it meets its users' needs, so a measurement of occupants' comfort with IEQ is an important part of assessing building performance and of addressing the main factors that affect occupants' comfort. The classification of physical indoor environmental variables was based on dividing the objective IEQ measurements for each factor equally into five indexes, depending on the maximum and minimum values, then participants' subjective answers were matched with the physical measurements in order to classify the IEQ categories precisely.

5.11. Conclusion

This chapter has reported the use of an artificial neural network to predict the relationship between indoor environmental quality and teachers' comfort, wellbeing and performance, using a multilayer perceptron and a backpropagation learning algorithm. There are several types of training algorithm, each with distinct properties, and it was important to test them in order to select the most suitable one for this study. TrainLM emerged as the best batch training algorithm for the purposes of the present study and was therefore used to develop the final model. The ANN contained three layers: input, hidden and output. The input parameters in the first layer were the physical variables of temperature, humidity, ventilation flow rate, CO_2 concentration, light condition and sound level. Various options were applied to choose the hidden layers and the different values of neurons to optimize the performance of the ANN. The output layer consisted of three neurons: comfort, wellbeing and performance. The hyperbolic tangent function was selected as the transfer function. The database was divided into three sections for early stopping: 70% of the data were used in training the networks, 15% as the validation set and 15% for testing.

The performance of the networks was evaluated by two criteria: coefficient of determination and mean square error about the modelled values. The model was developed in three stages to improve its efficiency. At the first stage, the numbers of neurons and layers were changed to maximize R values and minimize MSE values. It was found that the best network was ANN3-5, with three layers and five neurons (R = 0.9678, MSE = 0.0112). The purpose of the second stage was to develop momentum in the range 0.001-1. Only a small improvement was made, due to the high efficiency of the model. However, the model developed at this stage, ANN 3-5-2, did show improvement in R, MSE and gradient values: all R = 0.9694, MSE = 0.0108 and refined gradient = 0.005. Stage three was the development of the gradient curve, with values between 1-

e^3 and $1\text{-}e^{10}$; the resulting best model was ANN3-5-2-3, with $1\text{-}e^{7}$, all R = 0.9681, MSE = 0.008 and gradient = 0.0017. Moreover, in all of these models there was excellent agreement between experimental and forecast values, proving the strength and effectiveness of the ANN model. MSE and R values were close to each other, but ANN 3-5-2-3 emerged as the best network and was used to simulate new data, to explore the accuracy and efficiency of this model and to assess the relationship of IEQ with comfort, wellbeing and performance.

ANN3-5-2-3 was used to generate new data via mean values and standard deviation of input and output data after adjusting the skewness to give a normal distribution with log transfer function so that it would deliver perfect data. The comparison of these data using SPSS showed the model to be highly accurate, with a p-value of <0.05 and average values of comfort, wellbeing and performance of R = 0.92, indicating the relationship between IEQ and these three output parameters.

The classification scheme of IEQ and teachers' perceptions of these parameters determined the range of each indoor physical parameter that influenced teachers' comfort, wellbeing and performance, either positively or negatively. The average perceptions of users based on IEQ criteria in this study showed that 93% of these data were fitted to the participants' responses regarding the quality of the classrooms. Thermal comfort in this sensitive analysis was found to have the strongest positive effect, especially when temperature was 24.5-25.2 °C, humidity was 50-59% and ventilation flow rate was in the range 0.31-0.35 m/s, with an average of 58%, whereas the strongest negative effect was 32% for acoustic quality. The model identified the range of indoor environmental conditions that affected performance, based on survey responses, and correlated the relationship between IEQ variables and performance. The findings on these associations will be discussed in the next chapter.

Chapter 6

Discussion of Results and Findings

"A building can positively affect motivation by providing conditions that promote positive affective functioning, psychological engagement and personal control" (Heerwagen, 2000). This chapter discusses the results and findings of this study, addressing the association between indoor environmental quality and teacher performance. In doing so, it draws comparisons and contrasts with the findings of earlier studies. Weighted IEQ indexes are shown to be useful in determining the performance of individual aspects of the indoor environment and in exploring the effects of these attributes on teachers' comfort and performance.

6.1 Introduction

The quantitative relationship between IEQ and performance may vary, depending on other building features, on the characteristics of occupants' behaviour and on the type of task. Chapter 5 reported the implementation of the assessment model via ANN modelling to determine the relationships of IEQ factors with comfort, wellbeing and performance. The statistical values of parameters within this model generally indicate a significant relation between these input and output variables when R^2 is 0.9681 on all phases (training, validation and testing) and MSE is 0.0082.

A detailed examination of individual IEQ parameters recorded instrumentally shows that these features of the physical environment do predict the performance level of teachers, based on their survey responses. This chapter considers these findings and compares them with those reported in the literature, in order to better understand the relationship between IEQ factors and teachers' behaviour.

It is argued that the indoor environmental condition of buildings should be evaluated regularly in order to monitor the quality and efficiency of its parameters. The weighted IEQ index is an important tool for ranking these variables and for comparing the values obtained in this study with those reported in the literature reviewed in Chapter 2, because IEQ factors differ in the strength of their effect on performance.

6.2 The Effects of Indoor Environmental Quality on Performance

Most buildings in countries with a hot climate such as Saudi Arabia are fitted with HVAC systems in order to achieve optimum IEQ. Ventilation systems play a major role in controlling thermal comfort and IAQ. An investigation of IEQ in schools by Jurelionis and Seduikyte (2008) found that 64% of tested classrooms did not meet standards of thermal comfort and that inadequate ventilation in some classrooms resulted in high CO_2 concentrations. The study strongly suggests that physical indoor environmental factors forecast teachers' comfort with IEQ. This finding indicates the complexity of the effects on performance of overall comfort and comfort with several sensory domains. Moreover, measurements from one factor in the physical environment often predict IEQ comfort in a different case; for example, ventilation rate is a key determinant of CO_2 concentration and heating gain rate. This finding is consistent with Humphrey's (2005) observations regarding the complexity of attempts to develop a unified IEQ index that would be applicable to different building users.

The following subsections deal in turn with the effects on performance of each aspect of IEQ, namely thermal condition, IAQ, light quality, acoustic quality, layout and arrangement, biophilia and view, look and feel, and location and amenities.

6.2.1 Thermal condition and performance

Thermal comfort is one of the most significant IEQ variables and can be defined as that "condition of mind that represents comfort with the thermal environment" (Olesen and Parsons, 2002). Thermal comfort is determined by many parameters including air temperature, relative humidity, air velocity and radiant temperature. In addition, there are many personal factors, which affect thermal comfort, such as clothing insulation, task type, age and individual character (ASHRAE 55, 2013). In educational buildings, the importance of thermal comfort in the indoor environment should be considered, because many users work in limited spaces where safety and security are essential. Although the buildings studied in the present research were well equipped with HVAC systems, teachers were still exposed to the risk of sick building syndrome, whose symptoms are headache, mental fatigue, nausea and itchiness (Bluyssen, 2009; Codreanu, 2013). Wargocki and Wyon (2007) state that thermally uncomfortable conditions can make it more difficult for both teachers and students to complete their tasks and are likely to impair teacher performance.

This study measured temperature, humidity and the air velocity of mechanical ventilation, which determine thermal conditions, and has investigated the association between these parameters and performance. It was found that performance improved with increasing temperature up to 25 °C, with relative humidity to 68% and with ventilation flow rate to 0.32 m/s. The optimum values or ranges of these parameters for performance are 23-25 °C, 60-68% and 0.3 m/s respectively. However, the results show that it is possible to forecast changes in performance when they lie between 21.5 and 26.5 °C, between 30% and 75% and between 0.15 and 0.35 m/s.

These finding are in close agreement with those of Sarbu and Pacurar (2015) and of Kosonena and Tan (2004), who report that maximum performance was attained between 24 and 25 °C or at 27 °C in the cool season. They are also consistent with the finding of Fisk and Seppanen (2007) that performance deteriorated above 24.5 °C. Although, Witterseh et al. (2002) argue that there were no changes on tests when temperature in university classrooms increased from 22 °C to 26 °C and to 30 °C, and participants reported decreased self-estimated performance and increased difficulty in concentrating. Moreover, Cui et al. (2013) conducted subjective experiments to evaluate the influences of temperature on the performance of university students with a mean age of 22.3 years. They report no significant differences in performance between 22 °C and 24 °C or between 24 °C and 26 °C, but state that performance was significantly impaired when the temperature was increased further to 29 °C and to 32 °C. This may be because students feel clear-headed in a relatively cool classroom and sleepy in a warm environment. However, the average performance at 22 °C was not as good as at 26 °C, which suggests that a slightly cool to neutral environment is better for comfort and performance than a warm one. Another study by Witterseh et al. (2004) found that higher temperatures worsened a wide range of SBS symptoms, with negative effects on both comfort and performance. As air temperatures rose from 22 °C to 26 °C and then to 30 °C, SBS symptoms increased and occupants' performance declined.

Lee et al. (2012) investigated the effects of physical IEQ factors on students and university academic staff and found that occupants were most comfortable within the neutral temperature range of 21.5 °C to 23.5 °C. Their performance increased by 8% between these values, in contrast to the finding of Seppanen et al. (2004) that performance was unaffected by temperature in the range of 21 °C to 25 °C, but that it decreased by 2% per degree above 25 °C.

As to humidity, the findings of the present study are consistent with those of Ismail et al. (2008), who determined at a significance level of $p < 0.01$ that workers in the electronics industry were most effective when relative humidity was 59.5%. Likewise, (Sarbu and Pacurar, 2015) found that maximum performance corresponded to a relative humidity of approximately 60%. On the other hand, Tsutsumi et al. (2007) found that raising relative humidity from 30% to 70% significantly increased the rate of complaints among employees and indirectly affected performance level.

Mendell et al. (2002) conducted an experimental study in a warm climate, at a temperature range of 22.2 °C to 25.6 °C and indoor relative humidity of 40-50%, and found that SBS symptoms decreased by 12% to 24% per degree Celsius. The authors argue that this shows that it is mostly health and infections which affect performance.

In a study of call centre employees, Niemelä et al. (2001) found that their performance decreased by 1.8 % per degree of temperature above 25 °C. In a later study, Niemelä et al. (2002) report a fall in performance of 2.2% per degree above 25 °C.

The dexterity of hands and fingers is important in manual work and it may also be important for teachers and others who work with computers. Sepanan et al. (2004) report that temperatures below 25 °C have been found to be related to the performance of manual tasks by affecting dexterity. In tests of manual dexterity, performance has been found to depend on the temperature of the fingers and hands, which depends in turn on the thermal balance of the body. Humphreys et al. (1999) recorded large individual variations of finger temperature and room temperature. Their data show that a significant proportion of people have a finger temperature close to ambient globe temperature and that when this temperature is below 24 °C, there is a limit to the effect of temperature on manual dexterity. Mendell and Heath (2005) found that performance was impaired above 24 °C, while temperatures below 22 °C reduced manual dexterity and speed.

As to ventilation, the present study found that performance improved when the flow rate increased up to a limit of 0.40 m/s. This finding is similar to that of Wargocki et al. (2000), who report that increasing the ventilation rate improved performance on four simulated office tasks. They state that their results show that doubling the ventilation rate at constant pollution load can improve overall performance by 1.9%. In contrast, Federspiel et al. (2002),debate there was no significant association between performance and ventilation rate, but the authors report a 15% decrease in performance as the temperature increased from 24.8 to 26 °C when analysing individual performance on two tasks averaged over work shifts, found that talking tasks were performed fastest at the highest ventilation rates and similarly at the lowest ventilation rates. Correspondingly, when Fang et al. (2004) made a simpler comparison of two ventilation rates in the same controlled environment, they found no differences in work performance, an unexpected finding, which may be attributed to the limited of the collection data on this contrast.

Wargocki and Wyon (2013) state that classroom temperatures are commonly too high, not only in summer but also in autumn and winter, even in cold seasons, and argue that ventilation rates are inadequate to circulate fresh air and to reduce the heating gain caused by sunshine entering the glazed areas, which are typically designed to admit as much lighting as possible, with large windows facing the sun. Many schools in cold countries have only natural ventilation, but when external conditions are cold and windy, windows often remain closed to prevent draughts. While accepting that windows allow communication with nature as well as increased daylight levels, Hwang and Shu (2011) have demonstrated that temperature radiation and the thermal properties of the glazing influence the thermal comfort of occupants sitting near windows.

Additionally, Mysen et al. (2005), Wargocki (2008) and Zhang et al. (2010) have investigated thermal sensation, concluding that keeping the air dry and cool significantly and directly affects perceptions of IAQ. Improved performance is often a target in business and in academia, where reducing the temperature from 25 °C to 22 °C will tend to create a healthier environment, thus alleviating SBS symptoms, reducing absenteeism and potentially improving performance. Thermal environments also affect IAQ indirectly by influencing indoor concentrations of contaminants and emission sources. Increased ventilation is used to eliminate overheating, thus indirectly improving performance.

6.2.2 Indoor air quality and performance

It is often difficult to recognize the direct effects of IAQ on occupants' comfort and health in the presence of pollutants and other indoor environmental aspects. While much attention is given to reactive measures regarding indoor air quality, few studies are accessible to guide the construction of school buildings to enhance IAQ, minimize contamination and limit future hazards (Kamaruzzaman et al., 2011).

Generally, HVAC systems in the building envelope are the most common sources of IAQ problems, which can also be attributed to the building process phases including poor site selection, choice of materials, roof design and poor construction quality. However, the most significant element affecting microbial concentrations in schools was found to be high occupation density by students and teachers. Concentrations of TVOCs have been found to be strongly and positively related to CO_2 concentration and negatively to comfort with IAQ. Therefore, maximizing ventilation rates will not only lower CO_2 concentration but also remove indoor pollutants and improve comfort with IAQ (Kamaruzzaman et al., 2011).

Increasing CO_2 concentration results in reduced attention, loss of focus and tiredness, thus affecting performance negatively. The performance of teachers can be improved significantly by increasing ventilation flow rate and so reducing CO_2 concentration. The findings of this research indicate the relationship between CO_2 as an indicator of IAQ and performance, which is that performance improves when CO_2 concentration decreases; the optimal CO_2 concentration to maximize performance was in the region of 650 ppm. This finding is validated by the published finding that good air quality has a significant effect on performance in workstations (Kildes et al.,1999). A Danish study reported similar results, whereby when employees perceived that the air was fresh; they performed better, made fewer errors and experienced fewer SBS symptoms (Wargocki et al., 2002).

Sarbu and Pacurar (2015) found that above 850 ppm of CO_2, performance level was almost steady and that there was an insignificant decrease of less than 1%, even if CO_2 concentration was increased remarkably. Wargocki et al. (2007) assert that even a small improvement in air quality, corresponding to only 10% fewer users being uncomfortable with air quality, can improve performance by an average of 1.5%. Chatzidiakou et al. (2012) present evidence that performance improved when ventilation rates were above 8 l/s and 10 l/s. They state that CO_2 concentrations above 1000 ppm are associated with a 10-20% increase in absenteeism and argue that reducing CO_2 might therefore improve occupants' health and comfort, as well as their performance, which would enhance the learning process.

Wyon (2004) emphasizes the importance of designing ventilation properly because of its effect on the health and wellbeing of occupants. He argues that these effects are shown by the finding that when temperature was reduced by two degrees from 24.5 °C ($p < 0.05$) at the normal ventilation rate of 10 l/s, it was enhanced by 8.8%, which is lower than when the air supply rate was elevated to 23 l/s at the original temperature of 24.5 °C ($p < 0.04$). In a subsequent analysis of these effects, headache and difficulty in concentrating on a task were reduced by 19% ($p < 0.03$) and 13% ($p < 0.02$) respectively when the ventilation rate was approximately doubled to 40 l/s.

6.2.3 Light quality and performance

Designing lighting for buildings within global standards of illuminance is essential because each different task has a specific luminosity rate to establish visual comfort, due to variation in visual perception among users depending on age, individual characteristics and luminous environment. The spreading of light sources is an important factor of IEQ, with colour rendering index and colour temperature used to design the colour spectrum of light sources (Steffy, 2008).

The findings of this research indicate that performance improves when light level increases and visual quality is improved. The optimum measure of light condition for performance was when illuminance was in the range of 500 lux. However, it was observed that reflected light caused glare at high lighting intensity and that in response, classroom curtains were drawn to minimize the effects of glare. According to Hedge and Gaygen (2010), too much luminosity and dazzle in workplaces reduces occupants' comfort and performance; they also found that lighting needs vary according to task type and age.

Juslén et al. (2007) investigated experimentally the effects of light quality on speed of work and performance, concluding that speed increased by 2.9% when illuminance in the working environment was increased from 800 lux to 1200 lux.

Wyon (2004) found that designing lighting to provide illuminance of 500 lux, according to the recommended standard, was bright enough for work performance and usually more than adequate for visual comfort. It was concluded that teachers in the present study preferred to use artificial lighting and to keep blinds closed in order to minimize glare, because of the inappropriate window design and building orientation. Lee et al. (2012) found that university teachers in Hong Kong were most comfortable within the recommended desktop illuminance range of 300 to 500 lux.

Gou et al. (2013) reviewed several studies confirming a relationship between comfort and performance, finding that the most comfortable lighting conditions were between 401 and 500 lux, while accepting that for some visual tasks the optimum illuminance was found to be over 900 lux. Under stronger lighting, individuals may suffer mental fatigue; those exposed to illuminance of 1000 lux had slower responses on simple tasks and increased sleepiness, while their self-control improved.

The design of controlled daylight and suitable artificial illumination needs to be carefully implemented in classrooms, because lighting is critical to the quality of learning performance. Insufficient lighting control causes many health problems such as eyestrain and serious muscular pains, as well as raising body temperature in the case of excessive sunlight, with negative consequences for students' and teachers' performance (John and Timothy, 2005). However, many studies have discovered that access to daylight and fresh air can improve health, comfort and performance (Gregg and Ander, 2008). Two important purposes of window design are to facilitate the accessibility of and interaction with the natural environment and to allow daylight to enter the building, thus enhancing lighting quality, reducing energy costs and enriching visual quality. Conversely, occupants may suffer from heating gain via glazing areas, which will increase the load on the HVAC system in order to optimize thermal comfort, with undesirable effects on energy consumption.

Codreanu (2013) states that visual comfort is one of the physical features that determines the quality of light in buildings as well as occupants' perceptions of comfort with the indoor environment, which is a component of good IEQ. However, visual comfort is not assured unless illuminance levels are maintained at high quality.

In a statistical study of lighting in classrooms and its effects on the performance of students and teachers, the result of regression showed high values of R-squared and adjusted R-squared. Therefore, teachers and students were comfortable and light quality was acceptable. There was a significant association between lighting and performance as indicated by a beta value of 0.776 and a p-value of 0.000, which is less than 0.05 (Samani, 2012).

6.2.4 Acoustic quality and performance

The quality of the acoustic environment is related to several physical parameters, which include the physical properties of the sound itself and of the room. Sound-pressure level and sound frequency are the defining characteristics, although hearing varies by individual and age (Mehta et al., 1999).

The thermal comfort, indoor air quality and acoustic quality components are often related in buildings because noisy HVAC systems are used to control thermal requirements (Woo, 2010). It was found that acoustic perception decreased when thermal comfort was not in the neutral condition (Pellerin and Candas 2003; Pellerin and Candas 2004).

This research has elucidated the relationship between noise level, which determines acoustic quality, and performance, finding that performance improved when sound level was reduced. Sound level was recorded at between 48 and 77 dB, with 50 dB or less corresponding to the highest performance level. It was also found that neighbouring classrooms and corridors were the main sources of noise.

Zannin and Marcon (2007) found that noise levels in each of five classroom which they tested were above 40 dB. The same study found that both students and teachers identified classroom noise as a major source of disturbance to learning. In interviews, these participants asserted that annoying noise came mostly from other classrooms. They felt that teachers and students in adjoining classrooms spoke too loudly, which affected participants' ability to focus on their own lessons, with negative effects on their performance and outcomes.

The findings of this study are consistent with those of Wyon (2004), who found that distracting noise at 55 dBA in the workplace had a negative effect on the performance of complex tasks, although the rate of performance of some simpler tasks was improved.

The acoustic quality in classrooms also affects comfort and wellbeing, thus influencing teachers' performance and concentration on teaching. This statement corresponds to the finding of Toderașc and Iordache (2016) that comfort and performance were at maximum values when the noise level was 30 dB, whereas a level of 60 dB caused a sensation of discomfort.

Witterseh et al. (2004) studied the effect of two acoustic conditions on SBS symptoms and work performance. At a sound level of 55 dB, fatigue symptoms were reportedly higher and the ability to concentrate was reduced compared with 35 dB, which supports the argument that an excessive sound level can have negative effects on comfort and performance.

Shield and Dockrell (2008) correlated equivalent sound pressure levels in classrooms with students' and teachers' performance and found that both of these outcomes were impaired at levels above 60 dB, which suggests that loud outdoor noise can interfere with schoolwork performance.

6.2.5 Layout arrangement and performance

Classroom layout is an essential consideration for designers, because a more flexible and adaptable design has the ability to influence various curricular activities and lessons. Flexibility is important when considering spatial arrangements that allow teachers to redesign their classrooms to create more favourable and comfortable environments, which can enhance teacher comfort and the academic achievement of students (Bissell, 2004). The guidelines on classroom layout involve access to the outdoor environment and an average floor area of 2.1 m^2 for each student and teacher (BB 102, 2008).

As reported in Chapter 5, this research found a strong relationship between classroom layout and performance, while observation established that the classrooms were not overcrowded, with an average of 25 students in a class. As the rooms had an area of 72 m^2, the average area for each student was 2.85 m^2, which is more than recommended by standards such as BB 102 (2008). It was also observed that students were typically seated in rows on moveable chairs, providing flexibility by giving teachers the opportunity to adjust the layout, thus enhancing comfort and potentially improving performance.

These findings are consistent with those of Savage and Savage (2009), who conclude that the most common classroom layout, with rows of seating, can enhance learning and minimize student interaction. Moreover, many teachers stated that this arrangement created wide visibility, helping them to control students and assess their classwork, making them more likely to achieve curricular targets.

Minimizing the number of students per class allows teachers to optimize the layout and thus to improve their own performance and that of their students. Blatchford et al. (2002) found that test scores could be improved by reducing class size, but little change was noted between classes of 18 and 25 students. However, when class size was reduced to 15 students, there was some evidence of positive peer-to-peer interactions with consequent outcome improvement. On the other hand, Hargreaves et al. (1998) and Giles and Hargreaves (2006) observed 14 ‘expert teachers’ and found no statistically significant differences between large and small classes. Moreover, teachers still tended to address themselves to ‘groups’ of students, comprising the whole of a smaller class or part of a larger one, making greater use of ‘sustained interactions’ in smaller classes. When classes were smaller, teachers were also likely to engage in more enquiring questioning, ask more task-related questions and make more task statements.

In contrast, Zannin et al. (2013) found that both students and teachers preferred sociopetal classroom layouts, defined as encouraging social interaction among students, to seating in rows. However, advocates of teacher-centred learning claim just the opposite. The results of this study suggest that arranging seats in sociopetal alignments and using comfortable chairs for both students and teachers are valuable ways to improve performance.

Both layout and other aspects of furnishing can influence efficiency as well as individual task performance. Vischer (2007) reports that several studies have focused on the amount and accessibility of workstation space, as well as the height, density and quality of the furniture. These features of furniture and spatial arrangement have a significant effect not only on the comfort of individual occupants but also on the performance of teams.

The accessibility and quality of classroom equipment and furnishings are the most important factors affecting teaching performance, according to Lowe et al. (2003). Similarly, Douglas and Gifford (2001) found that the quality of school facilities including seating was a significant feature for students as well as teachers, who were more likely to report that lectures had gone smoothly if they had comfortable seats. The same study also concluded that other properties of classrooms, such as aesthetic appearance, brightness and size, were not rated as highly by teachers or students. In addition, Tanahashi (2007) reports that flexibility and ease of use of teaching equipment is important for teachers' self-confidence and argues that adapting classroom seating to suit different teaching styles might improve performance. The findings of layout design in this research and previous studies proved that the classrooms arrangement and number of students have a significant effect on teacher performance.

6.2.6 Biophilia & view and performance

Environmental psychologists theorize that an essential element of the relationship between a building's occupants and their physical environment is the perceived accessibility of nature (Evans, 2006). Enhancing the natural environment inside and around school facilities and creating a pleasing view have positive effects on the comfort and performance of both teachers and students. Thus, Heschong (2002) reports that it is beneficial to improve the workspace environment by designing windows to give workers a view outdoors, especially a view with natural features.

The finding of this study is that there is an association between performance and the view of the surroundings that could improve teaching outcomes. This is consistent with the finding of Wells and Evans (2003) that nature provided a buffer to stress after controlling for socioeconomic status and stressful life events. The authors argue that the mechanism through which nature buffers stress may be social, suggesting that access to nature and the landscape generates more opportunities for social activities. They also suggest that access to nature might improve concentration and performance.

This finding is equivalent to that of Newsham et al. (2009), who report that comfort with the outside view partly mediated the connection between potential exterior view and comfort with lighting. Improving the view of the environment was associated with comfort with outside view, which was correlated in turn with increased lighting comfort and thus affected performance level positively. Controversially, Borisuit (2014) found that a pleasant view from the window was positively associated with glare ratings that might minimize the quality of the lighting. The finding of this study was that in order to avoid the discomfort of strong glare, a direct outside view was prevented, but that this could lead to discomfort arising from poor daylight quality and visualization.

6.2.7 Look & feel and performance

Look and feel are described functionally in terms of suitable colours for learning environments as part of classroom design that could motivate students to learn better and teachers to perform more efficiently. A varied colour spectrum in the learning environment reduces boredom and passivity. It also affects students' achievement, as well as teachers' performance. The influence of colour is a significant element that directly affects people's emotions and may thus influence comfort and performance as well. Therefore, "classrooms should incorporate a variety of colours (based on gender, age, subject and activity) to reduce monotony and visually refresh perception" (Daggett et al., 2008).

This study has found a relationship between the look and feel of classrooms and teachers' performance. The classroom walls at JTC were observed to be a creamy colour, while the flooring consisted of beige tiles of 50 x 50 cm.

In a study of school classrooms, Yildirim et al. (2015) found that the indoor space of a classroom had a statistically significant effect on students and teachers in terms of perceptual performance. Their study examined three different colour types: a neutral cream, a warm pink and a cool blue. They argue that the blue-coloured space was perceived more positively than the cream and pink ones, being described as comfortable, peaceful and pleasant in comparison to the other colours.

The classrooms in the case study were decorated in neutral tones that were relatively bright. Hidayetoglu et al. (2012) investigated the effect of the brightness of colours in a space on perceptual performance, finding that students and teachers perceived the classroom more positively when the brightness level increased. They argue that this helps students and teachers to focus on the task in hand and could thus improve performance. In contrast, Hathaway (1987) assert that red, yellow and orange, being warm colours, are the most stimulating and will raise the level of interaction between students and teacher, whereas cool colours such as green and blue are less motivating in the classroom environment.

6.2.8 Location & amenities and performance

This study found evidence that teachers' performance was influenced by the college's location and amenities, in that the ease of access of the campus minimized the time and money that staff spent in travelling to work. Although the provision of public transportation was poor, the location of the college close to a major road meant that most members of academic staff spent on average no more than 30 minutes in travelling to or from work. This is consistent with a study by Tanner (2009), who found that the quality of school amenities was a significant attribute for both teachers and students, which could affect their performance in pursuit of learning objectives. It also accords with a review by Hanushek (1999) of 34 earlier studies in developing countries, which found a largely positive association between school facilities and learning.

6.3 Weighting IEQ Effects

Evaluations of performance have varied greatly from one study to another. The weighted sample size and unweighted regression models are based on the assumption that all measurements reflect the underlying performance equally well. Although the combined weights of variables takes account of the relevance of different performance measurements, the assignment of weights is complicated and involves subjectivity.

Concettina et al. (2012) and Heinzerling et al. (2013) explain that the weighting of comfort variables involves the examination of the associations among perceived comfort, environmental attributes and occupants' tasks. The purpose of a weighted index is to evaluate comfort with IEQ in order to allow comparison among indoor environmental factors and the performance of different buildings. Therefore, weights articulating a conventional ranking of comfort parameters with regard to indoor physical conditions should be suitable for the task of improving performance.

In the present study, the physical parameters of the indoor environment were measured instrumentally and evaluated by means of a survey. Questionnaire respondents were asked how the various IEQ factors had affected their performance and were invited to select their responses from five alternatives: very positively, positively, neutral, negatively and very negatively. These were then merged into three categories (positive, neutral and negative) to give a precise quantitative indication of the effect on performance. Figure 6.1 illustrates how each of eight IEQ parameters was found to affect the performance of teachers and potentially of the buildings themselves, which could help to evaluate their condition in terms of indoor environmental quality.

These parameters are appropriate indicators to explore the overall performance of teachers. Seven of the eight variables were found to have a positive effect on performance, whereas acoustic condition had a small negative effect. In more detail, thermal comfort had the strongest positive effect on performance, at 70%, followed by IAQ (65%), illumination level (57%), view and biophilia (55%), layout and arrangement (48%), look and feel (47%) and amenities and furniture (44%).

In contrast, the negative, neutral and positive effects of acoustic condition were evaluated at 36%, 30% and 34% respectively, indicating a very small overall negative effect, because of the limited space available to teachers and students, as well as the fact that dividing walls did not reach the ceiling in some classrooms. The weakest negative effects were those of thermal comfort and IAQ, at 11% of responses.

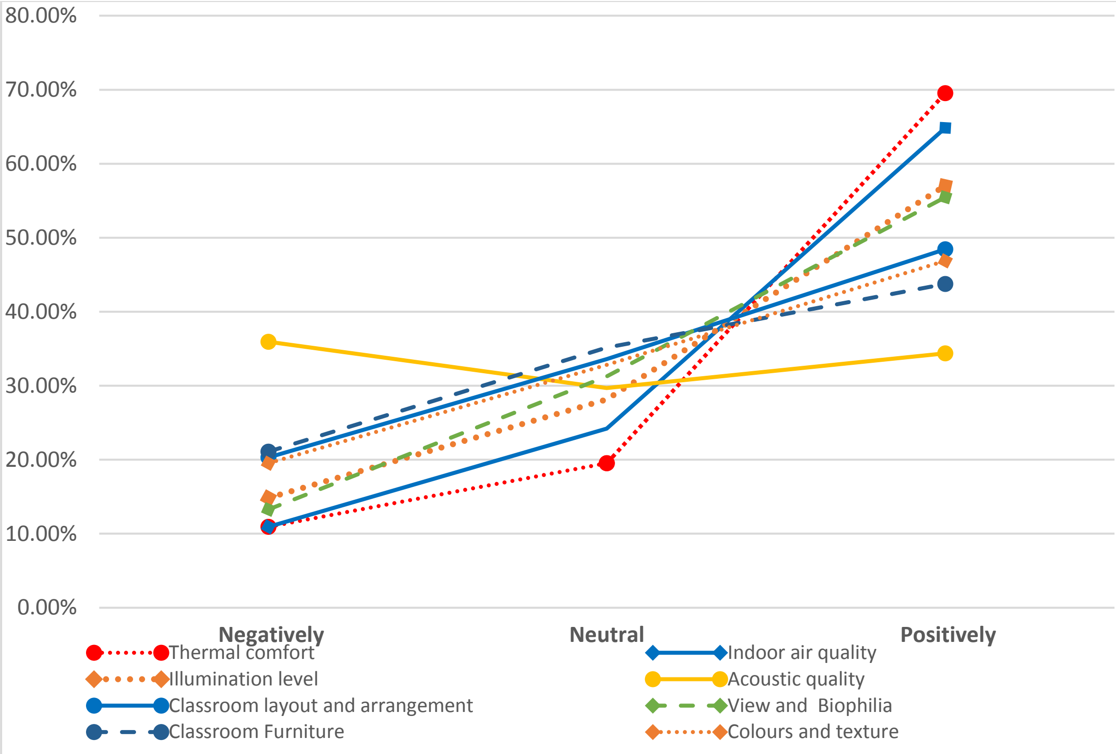


Figure 6.1: Effectiveness values of IEQ parameters on performance

Several studies have investigated the effects of IEQ on occupants' performance. These have ranked thermal comfort, IAQ, lighting and acoustic quality as the most important factors. Concettina et al. (2012) state that a weighted mean value gives a measure of the occurrence of environmental conditions that can be used to rank variables by the strength of their effects on performance. These weights facilitate the compilation of a hierarchy of comfort features with regard to the projected uses of environments which might be appropriate for given tasks.

Many studies that evaluate the effects of IEQ factors on comfort and performance have been reviewed in Chapter 2. In order to make comparisons with these studies, the mean values of the effects on teacher performance of thermal comfort, IAQ, light quality and acoustic quality were calculated in the present study and found to be 3.83, 3.72, 3.55 and 2.46 respectively. These attributes were then ranked by weighted mean value, even where tightly grouped together, with the result that thermal comfort was ranked 4, as the variable with the strongest effect on performance, followed by IAQ, light quality and acoustic quality in that order. Figure 6.2 illustrates the various weighted effects of IEQ factors on performance according to the present study and ten others, evaluating IEQ factors on a four-level scale where level 4 represents the strongest effect and level 1 the weakest. For example, Wong et al. (2015) rank acoustic quality as having the strongest effect on performance, followed in order by IAQ, thermal comfort and light quality. In contrast, Barret et, al. (2015) found acoustic quality to have the least effect, while light quality was the factor exerting the strongest influence on performance. As Figure 6.2 shows, almost half of the eleven studies, namely the present study and those of Humphreys (2005), Wong et al. (2008), Lai and Yik (2009) and Cao et al. (2012), conclude that thermal comfort is the variable with the strongest effect on performance.

The present study is thus consistent with Humphreys (2005) and Wong et al. (2008), having found that thermal comfort was the parameter with the strongest effect, followed by IAQ, whereas light quality and acoustic quality were the least effective parameters, in line with Lai and Yik (2009).

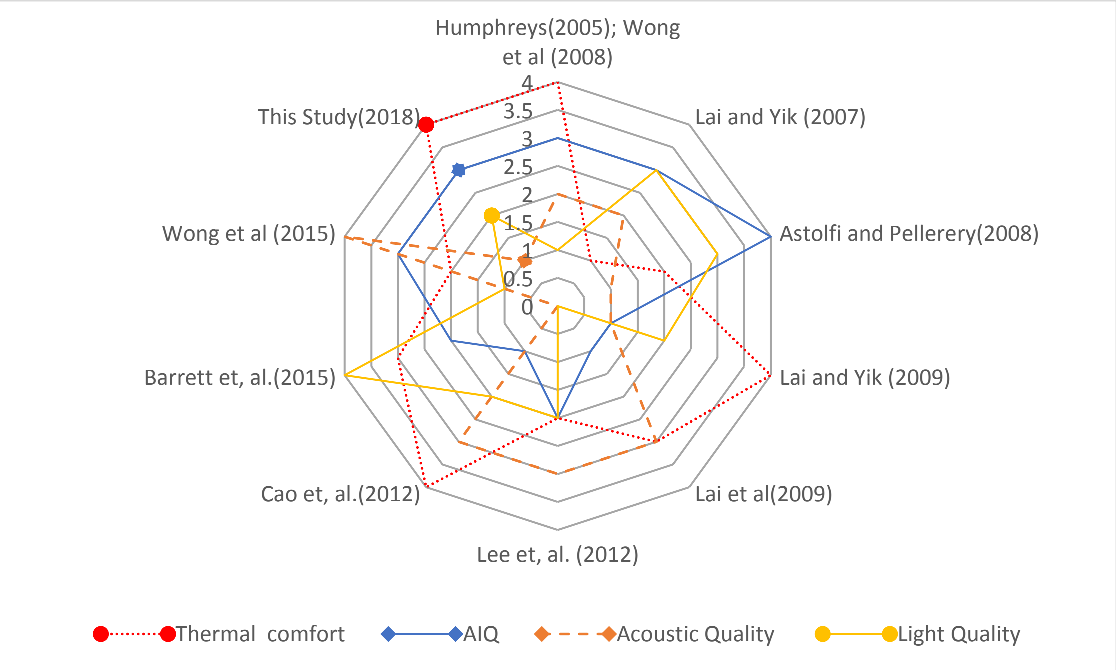


Figure 6.2: Weighted effects of IEQ factors on performance

6.4 Conclusion

The quality of physical indoor environmental attributes have been the subject of a number of past studies. The quality of the indoor environment of schools is considered a key concern in pursuit of an enhanced learning process, better student outcomes and improved teacher performance. These IEQ factors were found to affect teachers' performance, the relationship which this study has addressed. The results strongly indicate that differences in the quality of the physical environment correspond to variations in performance level. This finding is generally consistent with those of previous studies reported in the literature which have linked the physical environment of educational premises to teachers' performance.

Calculating the weights of all physical indoor environmental parameters facilitates the classification of the elements of IEQ, allowing the comparison of the performance of building environments so that good indoor environments can be distinguished from poorer ones. Kim and de Dear (2012) assert the importance of weighted IEQ variables in identifying those features having the greatest effects on occupants' comfort, due to the existence of a relationship between comfort and building performance. Thermal comfort is considered the most effective factor and acoustic quality the least.

This chapter has discussed the findings of the present study in light of the literature reviewed earlier. The next concludes the thesis.

Chapter 7

Conclusion

The aim of this research was to investigate the relationship between indoor environmental quality and teacher performance. A model to study this association was developed. This concluding chapter discusses how the study aim was fulfilled, how the objectives were achieved and what limitations were tackled during the research. Contributions to knowledge in the field of IEQ are outlined and lines of future research are suggested.

7.1 Introduction

Buildings are constructed with the expectation of providing their occupants with an acceptable quality of indoor environment, such that their comfort, wellbeing and performance are not negatively affected. The concept of IEQ has come to the forefront in recent years and become a contentious topic of debate due to its effects on occupants' performance.

In the educational context, IEQ includes many variables that have an effect on teachers' performance, such as thermal comfort, indoor air quality, lighting quality, background noise, ventilation rates and ergonomics. The network of relationships among these parameters makes the study of IEQ complex. A study of all individual parameters and their relations one to another is essential to understand this intricate system. A review of the literature suggests that thermal comfort is the IEQ variable most often investigated, due to its close associations with heating, ventilation and air-conditioning and by extension with energy consumption, which is considered the main driver of green building. The literature reviewed in Chapter 2 was concerned with defining and appraising the concept of IEQ, studying its relationship with performance and investigating the factors affecting that relationship.

Most of the empirical studies in the field have taken place in developed countries and been set in offices, whereas few have investigated the environments of school buildings and scholars have claimed that studies of IEQ specifically concerned with developing countries are still limited in number and scope. The present research was conducted in response to the need to expand knowledge in this area by exploring the quality of the physical indoor environment in educational buildings and its effect on the performance of teachers in developing countries.

The aim has thus been to develop a model for assessing the effects of indoor environmental quality on teachers' performance in Saudi educational buildings. This chapter summarizes the methods that were implemented to achieve this aim, their implementation and results, identifies the contributions of the study to knowledge, recognizes its limitations and makes suggestions for future research.

7.2 Research Objectives Revisited

The outcome of this research is the construction of a model with specific guidelines to explicate the relationships between IEQ factors and teachers' performance. This was accomplished by addressing the following objectives:

- To identify the relevant physical indoor environmental variables by means of a review of the literature (Chapter 2) and to investigate the effect of their quality on teachers' performance in Saudi schools.

- To conduct a case study and survey in Saudi school buildings to assess the quality of the indoor physical environment and to revise the data based on the preliminary results and findings (Chapters 3 and 4).

- To develop a model of the physical indoor environmental factors identified by the literature review for Saudi schools (Chapter 5).

- To classify (by means of weighting schemes) the effects of physical indoor environmental factors on teachers' performance in Saudi educational buildings and to compare the results with published findings (Chapters 5 and 6).

7.2.1 Effects of the physical indoor environment on teachers' performance

Various studies have investigated the effects of the physical indoor environment on occupants' comfort and performance. There are many aspects of environmental comfort, including physical ones such as air quality, thermal quality, noise and light, aspects of functional comfort related to tasks and activity types, and psychological factors such as privacy and safety. However, this research has focused on comfort in terms of physical indoor environmental parameters such as air quality, light, noise and thermal conditions, spatial configuration including room layout, the external environment (view and biophilia) and the aesthetic elements of colour and texture (look and feel).

Some studies have explored the effect of IAQ on performance, often using CO_2 level as an inverse indicator of ventilation rate and the delivery of fresh air to occupants. Raised levels of indoor air pollutants including CO_2, caused by inadequate ventilation in classrooms, may impair learning processes and outcomes by increasing tiredness and loss of attention. Conversely, higher ventilation rates indirectly improve learning outcomes and performance, because good air quality enhances teachers' comfort and health, thus reducing absenteeism and strengthening motivation to teach.

There is a wide range of factors with direct and indirect effects on comfort. Thermal comfort, for example, is affected by three physical parameters, which are air temperature, relative humidity and air velocity, and by personal characteristics including gender, age, clothing, task types and individual differences. Moreover, the range of temperatures within which occupants are comfortable cannot be determined absolutely because of the diversity of environmental, geographical and personal factors that come into play. However, a few studies have sought to establish the extent to which perceptions of comfort affect academic performance. Generally, the review found that thermal comfort has been shown to have a significant effect on the overall morale, performance and wellbeing of classroom occupants. In addition, thermal discomfort in classrooms may create conditions for both teachers and students that increase the incidence of complaints, aggressive behaviour and inability to concentrate.

The purpose of lighting design is to ensure visual quality in a space, thus contributing to a healthy environment and improving the achievement of tasks. Several researchers have indicated that the quality of light in buildings has a direct effect on mood, which can influence performance rate. It is essential to design an appropriate environment where occupants of buildings will be comfortable and healthy, both physically and mentally. Conversely, a visually uncomfortable environment, caused by inadequate lighting quality and poor design, can cause depressive moods and an inability to concentrate. Furthermore, teachers may feel sick because of forcing their eyes to adapt very quickly to varied light intensities, which is not only distracting and stressful but also potentially damaging to the eyes. Consequently, some authors have suggested that using daylight and controlling glare will have positive effects on performance because artificial light involves electromagnetic rays that can cause headaches and eyestrain.

While physical properties of a room such as sound insulation materials and reverberation time influence acoustic quality, the human perception of noise comfort depends on personal characteristics and external factors such as noise sources. This indicates that individuals' perceptions differ as to the relative importance of overall background noise levels and the extent to which noise distracts them from the task in hand. However, the literature review has established that a suboptimal acoustic environment in a classroom will influence the quality of speech communication, impairing the performance of students and causing teachers to suffer from tiredness. The quality of sound in classrooms is a major factor that should be considered, because exposure to high levels of sound interferes with communication and disrupts the learning process, leading to a loss of concentration, higher levels of task error for teachers and students.

Classroom layout reflects the variety of educational philosophies and understandings in different cultures and countries. The style and arrangement of furniture are major issues in space management that should be considered carefully by designers, because the flexibility and adjustability of design have the potential to affect various lesson activities. Flexibility is important when considering spatial arrangements that allow teachers to modify their classrooms to create positive and comfortable environments, which can enhance teacher comfort and improve the academic achievement of students. Moreover, the selection of appropriate classroom furniture makes the space more attractive and comfortable, while adjusting the layout can have positive effects on the performance and morale of both teachers and students, thus advancing learning outcomes.

Designing classrooms so that they are open to views of nature plays a powerful role in the wellbeing of occupants, because the human brain evolved in a natural setting. Therefore, many researchers have shown that employees with a natural view exhibit less job pressure, are more comfortable and recover from stressful situations more quickly. Some scholars have argued that the mechanisms by which nature limits stress may be social, suggesting that access to nature and the countryside generates more opportunities for social activities, which might in turn improve concentration. In the natural environment, people have higher levels of happiness and wellbeing, because views of nature through windows create a positive mood and may reduce stress and anxiety, helping occupants to perform better.

Aesthetic factors including colour and texture were found to be the least significant, since users acknowledged less of an impact on them than that of other IEQ factors which functionally affected them directly; the influence of aesthetics on performance was also less evident. While occupants' reactions to different colour schemes depend on their culture, education and genetics, it has been established that colour influences wellness and mood, thus indirectly affecting performance. Therefore, appropriate colours should be carefully selected to improve teachers' performance, because a good colour scheme can instil a sense of quiet and comfort that affects them psychologically, ensuring a positive mood.

The location of any educational establishment considers an important variable in the comfort of students and teachers by affecting their ease of access, especially when a site is difficult to approach because of its distance from the occupants' homes or the inadequacy of public transportation. As to amenities, if the educational buildings support a variety of learning experiences for students and diverse work experiences for administrators and teachers, these can affect the health and safety of all users and the success of educational programmes.

7.2.2 Evaluating the quality of the physical indoor environment

This research used a specific case study and adopted two strategies, namely experiment and survey, to determine the quality of the physical indoor environment of college classrooms and its effect on teachers' performance. It employed digital instruments, each combining several sensors, to measure the IEQ parameters of interest, which were the thermal, acoustic and lighting conditions of their classrooms. While these physical readings were being taken and recorded, the teachers were surveyed for their perceptions of comfort with their classrooms. The advantages of the survey approach are the low cost of questionnaires, the short time needed to collect data and the ability to elicit participants' perceptions of several variables at once. Because each teacher was surveyed at the same time as physical measurements of his actual classroom environment were being made, it was possible to benchmark these objective data against established standards and the teachers' perceptions.

Contemporaneously with the taking of measurements and the administration of surveys, observations were made to gather other relevant data such as weather conditions, the number of students in the class and the teaching equipment (monitors, projectors and printers) available in the classroom being evaluated, as well as its decor, layout and other physical characteristics.

Cronbach's alpha was used to determine the reliability of the questionnaire items on indoor environmental parameters affecting the degree of comfort, wellbeing and performance. The reliability test showed that consistency between answers was 87.2% ($\alpha = 0.872$), which represents a good standard of reliability of those elements.

Among all of the measurements of physical indoor environmental parameters taken in classrooms, the proportion which fell within the range of recommended standards was 84% for temperature, 92% for relative humidity, 87% for CO_2 level, 88% for light level and only 47% for sound level. The physical IEQ of the case study teaching premises was thus found to be high in terms of the first four of these parameters, but poor in terms of background sound level.

7.2.3 Indoor physical environment assessment model

The third objective of this research was to construct a model for assessing the association between indoor environmental quality and teacher performance. Fulfilling this objective was considered one of the major tasks of this study and an artificial neural network was used to elucidate this relationship. This was successfully achieved by taking a series of steps, as follows:

- Normalising input and output data in the range (-1,1) using appropriate formulae, to make the data comparable, because of the variation in scales of measurement of IEQ factors and in survey scales.
- Determining a suitable algorithm with which to train the ANN, because there are many such algorithms having different training functions.
- Constructing an ANN model and developing it to improve its efficiency in three stages: editing the number of neurons and layers, developing the momentum of the model and developing gradient values.
- Creating new data based on the mean values and standard deviations after normalising the skewed distribution.
- Simulating new data to test the accuracy and efficiency of the model and comparing the results with original data in the SPSS program.

The architecture of the ANNs was designed to create and develop a model to evaluate the association between IEQ and teacher performance. The networks consisted of neurons, topologies and weights. The neurons were of three kinds: input neurons, hidden neurons and output neurons. The most popular batch training algorithm was tested to explore the efficiency of the primary network, then this model was developed to maximize the R-value and minimize the MSE value in a process explained in Chapter 5 (Section 5.7). The final assessment model, as depicted in Figure 5.15, was ANN3-5-2-3, which was determined to be the best for generating new data. The new data were then assessed on SPSS, which indicated high efficiency of all statistical values of the output data ($p<0.01$) and average R^2 was 0.932, indicating a significant correlation between physical indoor environmental variables as input data and comfort, wellbeing and performance.

7.2.4 Classification of physical indoor environmental factors

Teachers' comfort in the classroom is correlated with the quality of the indoor environment and building elements, which directly affects performance. The survey and objective measurements of physical IEQ were rich sources of data on those conditions that reflect the reality of building performance and which may therefore be of concern to the sponsors. Thus, it is essential for the condition of these buildings to be evaluated for its effects on comfort, health and performance. Previous studies have used this method to inspect the association between physical measurements and the subjective perceptions of occupants.

The importance of categorizing these indoor environmental variables lies in their status as indicators of a building's condition related to the comfort, health and performance of the occupants. This classification correlates subjective assessments elicited by means of a survey with objective measurements in order to determine occupants' comfort in relation to each IEQ factor.

In order to fulfil this objective, the readings of each indoor environmental parameter were divided equally on a five-point scale to make them comparable with the questionnaire responses, then the record of each parameter was matched with the corresponding survey result (Chapter 5, Section 5.6). Once this classification was completed, it was used as the basis for determining the relationships between IEQ parameters and performance.

7.3 Research Contributions

This study is important because the performance of teachers in schools and colleges is a source of concern for society, parents and governments, especially in developing countries, where limited studies have been conducted in this field. Most of the studies that have explored the effects of IEQ have been set in office buildings, while few have focused on schools. Furthermore, those that have investigated the effects of the physical condition of school buildings on comfort and performance have tended to be concerned with these outcomes among students rather than teachers. Consequently, the significance and originality of this research lie not only in its being the first to consider a wide range of IEQ parameters rather than just one factor (e.g. thermal comfort) to evaluate the condition of educational buildings scientifically, but also in its focus on the comfort and performance of teachers.

This research has also made the following contributions of value to both academics and practitioners:

- It adopted a comprehensive methodology to evaluate IEQ and teacher performance in academic buildings as well as emerging and validating an assessment model to achieve its objectives. This methodology can be enhanced by other researchers and practitioners to evaluate the effects on performance of existing school conditions, in order to improve their quality and operation. It could also be used to develop new school designs, thus providing enhanced conditions for students, teachers and other school employees.

- It will assist administrators in launching properly directed educational policies addressing the issues of IEQ in educational buildings in order to improve teachers' performance. Furthermore, the results of this research may guide and encourage businesses, building owners and designers to make informed design decisions about IEQ.

- The findings of this study can be used to advance designers' knowledge of IEQ in higher education classroom environments. This provides an opportunity for educational institutions to use knowledge of the physical classroom environment as a design guide to enhance student outcomes and teachers' performance. Given the large numbers of indoor environmental variables that affect teachers' comfort and performance, it is essential for designers to recognise the effects of individual variables, specifically those that are within designers' control.

- The findings can also be benchmarked against similar occupancy and building types, adding to the existing body of knowledge on indoor environmental quality, especially in developing countries.

- This study provides a fundamental database for evaluating aspects of IEQ in academic buildings. These data can be developed significantly through future contributions of other studies that can help to classify common trends of IEQ and teacher performance in other school buildings across the country. Similar datasets can be constructed for existing schools, identifying any problems of environmental quality so that these can be addressed, thus helping to enhance their current quality and to improve their operation and maintenance by providing enhanced conditions for teachers, students and other school staff which will benefit their future performance. Finally, this methodology and these data can be applied to new school designs to provide suitable IEQ standards and thus to ensure high levels of comfort and performance for teachers.

7.4 Limitations and Further Research Directions

The scope of this research was specifically the physical IEQ parameters of the educational buildings in which this study was conducted. Therefore, the validity of the model developed to evaluate the effects of these factors on performance is limited to academic buildings where HVAC systems are in constant use, excluding those that rely wholly on natural ventilation. Such buildings do not exist in the region where the case study was conducted, because of its hot climate; a comparative study of buildings in a different environment might be expected to have significantly different findings. When the HVAC system was controlled during one measurement period to investigate the effects of variation on comfort and performance, the teachers and students complained and left their classrooms. It is therefore suggested that a number of case studies be conducted under a variety of indoor environmental conditions for comparison purposes and to assess the breadth of applicability of the research model.

The research, which involved making objective measurements and eliciting subjective assessments, was limited by its focus on teachers alone, in common with several earlier studies. Surveying both students and teachers would have provided a more comprehensive assessment of comfort and performance, especially since students make up a major proportion of the college population. However, researchers planning such an expanded study sample should note that a recent review of the literature found that students might not always entirely understand questionnaire approaches and respond applicably to them.

This research depended on the statistical treatment of specific physical indoor environmental factors and controlled for certain variables. A limitation is that many other variables might have influenced the results if they had been included; therefore, these would need to be considered in future studies. These absent variables concern physical and psychological attributes such as behavioural factors associated with teachers' and students' use of classrooms, technical components including the configuration of the HVAC systems and financial factors related to the operation and maintenance of the buildings. If included in future studies, these would potentially have a significant impact on the results.

Consideration of these limitations could guide and orient future research, which should focus on assessing a broad sample of schools and classrooms using on-site physical readings and repeating these strategies throughout an academic year to investigate the effect of weather conditions on indoor features and occupants' perceptions of them. Many previous studies have measured physical indoor variables and sought to correlate them with survey data gathered at a different time. Future researchers should emulate the present study by taking physical measurements of IEQ at the same time as surveying users, to eliminate the possibility that changes in conditions or occupancy might distort the results.

Finally, while this study adopted three data collection strategies, it is highly advisable for future research to gather additional data by means of focus groups or interviews to add depth to the understanding of indoor conditions, as well as to test the model developed here with different data analysis techniques. Future studies could also broaden the focus by measuring not only physical IEQ but other variables such as rates of absenteeism among teachers, their extra effort, student feedback and grades, as criteria by which to assess teachers' performance.

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Appendices

- **Appendix I: Ethics approval**
- **Appendix II: Questionnaire**
- **Appendix III: Full measurement schedule**
- **Appendix IV: Measurements of physical indoor parameters in all classrooms**
- **Appendix V: Results of experimental models**

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3 January 2017

Hamdan Alzahrani

Dear Hamdan,

RE: ETHICS APPLICATION STR1617/20 – The Impact of Indoor Environment Quality on Teacher Performance in Educational Buildings

Based on the information you provided, I am pleased to inform you that your application STR1617-20 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

[redacted]

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Indoor Environment Quality Survey

Classroom Information	Building Code	Classroom Number	Lecture Period	Academic Semester

Section A: Demography

1- What is your age?
   a. 30 or under
   b. Between 31-40
   c. 41-50
   d. Over 51

2- How long have you been working in this college?
   a. Less than 1 year
   b. 1-2 years
   c. 3-5 years
   d. More than 5 years

3- How many hours do you spend in classrooms per week?
   a. 10 or less
   b. 11-15
   c. 16-20
   d. More than 21

4- What is your highest educational qualification?
   a. Bachelor degree
   b. Master degree
   c. Doctorate degree
   d. Others

5- On average, how many students do you have in your most frequent classroom?
   a. Less than 15
   b. Between 16-20
   c. Between 21- 25
   d. More than 26

Section B-1: Classroom's Physical Survey

6- What is the agreement level toward these factors in your classroom?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Classroom layout and arrangement is comfortable.					
Classroom size is comfortable.					
Students' number in your classroom is comfortable.					
Colors and texture in your classroom are comfortable.					
Classroom furniture and equipment are comfortable.					

Section B-2: Thermal comfort

7- What is the agreement level toward thermal conditions in your classroom?

Indoor environment factors	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Classroom temperature is suitable					
Classroom humidity is suitable					
Ventilation level in your classroom is acceptable					
Thermostat is accessible to control thermal comfort					
Overall, thermal condition in your classroom is comfortable					

8- How would you describe your thermal sensation in your classroom?

A. Hot
B. Warm
C. Slightly warm
D. Neutral
E. Slightly cool
F. Cool
G. Cold

Section B-3: Air Quality

9- What is the agreement level toward Air Quality in your classroom?

Indoor environment factors	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Air in your classroom is stuffy/stale					
Air in your classroom is not clean.					
Air in your classroom smells bad (odors)					
Overall, air quality in your classroom is acceptable					

Section B-4: Lighting Quality

10- What is the agreement level toward lighting Quality in your classroom?

Indoor environment factors	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Daylight in your classroom is enough.					
Artificial light in your classroom is adequate.					
Visual condition (glare, reflection,) in your classroom is comfortable.					
The ability to control the amount of light in your classroom is reachable.					
Overall, lighting quality in your classroom is acceptable					

11- Which of the following control set do you have over the lighting in your classroom? (check all that apply).

a- Window blinds or shade
b- Light switch
c- Light dimmer
d- None of the above
e- Others

Section B-4: Acoustic Quality

12- What is the agreement level toward these noise sources in your classroom?

	Strongly Disagree	Disagree e	Neutral	Agree	Strongly Agree
There is a noise from heating, ventilation, and cooling system					
There is a noise from other classrooms					
There is a noise from outdoors (Cars, Traffic, Parking, ..)					
There is a noise from teaching equipment					
Overall, acoustic quality in your classroom is acceptable					

Section C: Indoor Environment Quality and Performance

13- How have these factors affected your performance?

Indoor environment factors	Very Negatively	Negativ ely	Neutral	Positi vely	Very Positively
Thermal comfort					
Indoor air quality					
Illumination level					
Acoustic quality					
Classroom layout and arrangement					
View and visual comfort					
Colours and texture					
Classroom Furniture					

14- How have these factors affected your well-being and health?

Indoor environment factors	Very Negatively	Negatively	Neutral	Positively	Very Positively
Thermal comfort					
Indoor air quality					
Illumination level					
Acoustic quality					
Classroom layout and arrangement					
View and visual comfort					
Colours and texture					
Classroom Furniture					

Thank you

Full measurements schedule

Class rooms	8:00 am	Morning reading schedule						10:00 am	Mid-day reading schedule						12:00 am	Afternoon reading schedule						3:00 am
	Outdoor reading	8:15-9:45						Outdoor reading	10:15-11:45						Outdoor reading	1:15-2:45						Outdoor reading
D102			×						×							×						
D103		×									×						×					
D104				×						×									×			
E101						×							×					×				
E106							×							×							×	
G103					×							×								×		
F104		×								×						×						
E102				×					×								×					
F001			×								×							×				
C104					×									×					×			
G104							×						×								×	
C107						×						×								×		
D110		×							×							×						
F113			×								×						×					
F111						×				×									×			
C110				×								×						×				
G104							×							×						×		
E104					×								×								×	
D101		×							×								×					
F103				×							×					×						
F106			×							×								×				
C106						×							×						×			
G111							×							×							×	
F110					×							×								×		
D207			×							×								×				
E204		×									×						×					
F204						×			×										×			
C204				×										×		×						
C205							×						×							×		
G204					×							×									×	
D215			×						×							×						
D213		×									×						×					
G211				×						×									×			
C207					×								×					×				
E206							×							×							×	
E207						×						×								×		
C207							×		×									×				
C206						×					×						×					
F211				×						×									×			
C111					×								×			×						

							Outdoor reading							Outdoor reading							Outdoor reading
C208		×											×							×	
F107	×										×								×		
D009		×						×							×						
D010	×									×								×			
F009					×								×			×					
C005			×									×					×				
E001						×			×											×	
G009				×							×								×		
C001		×						×							×						
C002			×							×						×					
G001	×												×					×			
D001					×							×					×				
E010						×			×											×	
C003				×							×								×		
C004	×							×								×					
G008		×							×						×						

Measurements of physical indoor parameters in all classrooms

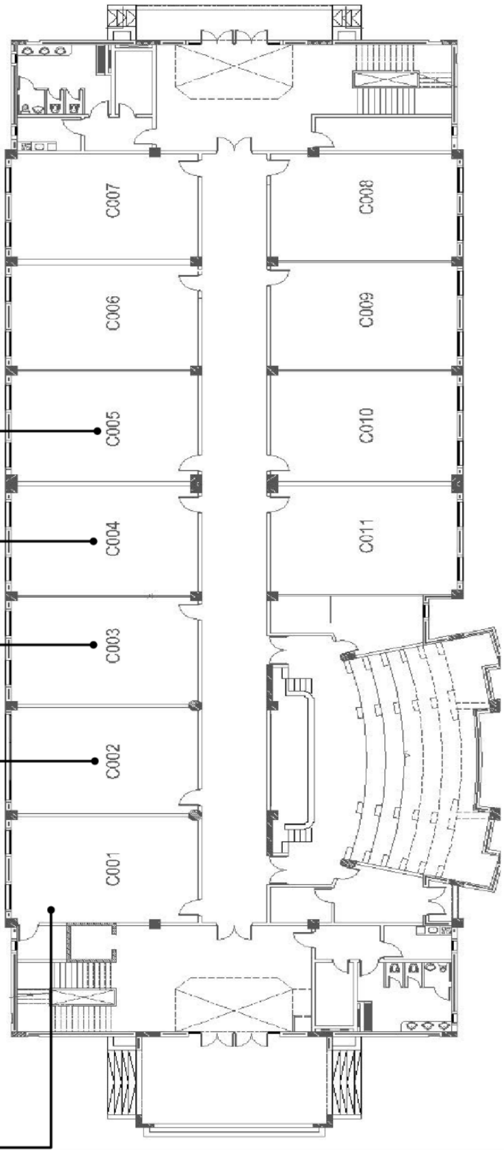
BLD code	CLS code	Variables	period	< Recommended value <
C	5	Temperature (T)	8:15-9:45	23.60
			10:15-11:45	24.50
			01:15-2:45	23.40
		Humidity (H)	8:15-9:45	53
			10:15-11:45	48
			01:15-2:45	55
		Co2 level(CO2)	8:15-9:45	855.73
			10:15-11:45	834.02
			01:15-2:45	818.22
		Noise level(N)	8:15-9:45	63.17
			10:15-11:45	64.16
			01:15-2:45	47.38
		Lighting level (L)	8:15-9:45	310.76
			10:15-11:45	401.40
			01:15-2:45	445.79
		Ventilation rate (V)	8:15-9:45	0.25
			10:15-11:45	0.30
			01:15-2:45	0.25

BLD code	CLS code	Variables	period	< Recommended value <
C	4	Temperature (T)	8:15-9:45	22.60
			10:15-11:45	23.70
			01:15-2:45	24.87
		Humidity (H)	8:15-9:45	59
			10:15-11:45	53
			01:15-2:45	43
		Co2 level(CO2)	8:15-9:45	783.00
			10:15-11:45	772.00
			01:15-2:45	656.00
		Noise level(N)	8:15-9:45	51.50
			10:15-11:45	71.20
			01:15-2:45	62.30
		Lighting level (L)	8:15-9:45	336.00
			10:15-11:45	321.00
			01:15-2:45	329.00
		Ventilation rate (V)	8:15-9:45	0.35
			10:15-11:45	0.30
			01:15-2:45	0.28

BLD code	CLS code	Variables	period	< Recommended value <
C	3	Temperature (T)	8:15-9:45	23.60
			10:15-11:45	22.90
			01:15-2:45	22.60
		Humidity (H)	8:15-9:45	50
			10:15-11:45	53
			01:15-2:45	55
		Co2 level(CO2)	8:15-9:45	686.95
			10:15-11:45	682.02
			01:15-2:45	678.07
		Noise level(N)	8:15-9:45	47.57
			10:15-11:45	52.31
			01:15-2:45	51.32
		Lighting level (L)	8:15-9:45	363.29
			10:15-11:45	422.86
			01:15-2:45	388.45
		Ventilation rate (V)	8:15-9:45	0.25
			10:15-11:45	0.30
			01:15-2:45	0.30

BLD code	CLS code	Variables	period	< Recommended value <
C	2	Temperature (T)	8:15-9:45	22.30
			10:15-11:45	24.10
			01:15-2:45	25.60
		Humidity (H)	8:15-9:45	51
			10:15-11:45	50
			01:15-2:45	53
		Co2 level(CO2)	8:15-9:45	867.00
			10:15-11:45	789.00
			01:15-2:45	792.00
		Noise level(N)	8:15-9:45	62.80
			10:15-11:45	53.10
			01:15-2:45	71.90
		Lighting level (L)	8:15-9:45	362.00
			10:15-11:45	351.00
			01:15-2:45	373.00
		Ventilation rate (V)	8:15-9:45	0.35
			10:15-11:45	0.25
			01:15-2:45	0.25

BLD code	CLS code	Variables	period	< Recommended value <
C	1	Temperature (T)	8:15-9:45	25.60
			10:15-11:45	24.80
			01:15-2:45	23.90
		Humidity (H)	8:15-9:45	44
			10:15-11:45	50
			01:15-2:45	53
		Co2 level(CO2)	8:15-9:45	854.74
			10:15-11:45	864.61
			01:15-2:45	868.56
		Noise level(N)	8:15-9:45	61.19
			10:15-11:45	55.27
			01:15-2:45	48.36
		Lighting level (L)	8:15-9:45	416.20
			10:15-11:45	388.45
			01:15-2:45	373.65
		Ventilation rate (V)	8:15-9:45	0.15
			10:15-11:45	0.30
			01:15-2:45	0.30



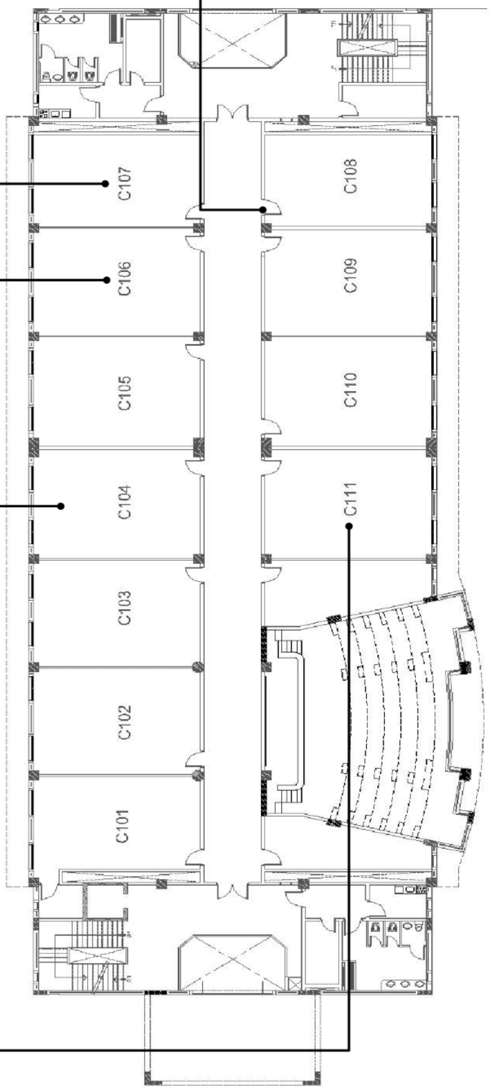
BLD code	CLS code	Variables	period	<	Recommended value	<
C	110	Temperature (T)	8:15-9:45		24.60	
			10:15-11:45		25.80	
			01:15-2:45		23.80	
		Humidity (H)	8:15-9:45		35	
			10:15-11:45		44	
			01:15-2:45		47	
		Co2 level(CO2)	8:15-9:45		848.80	
			10:15-11:45		861.85	
			01:15-2:45		855.74	
		Noise level(N)	8:15-9:45		63.54	
			10:15-11:45		74.34	
			01:15-2:45		75.33	
		Lighting level (L)	8:15-9:45		448.00	
			10:15-11:45		433.00	
			01:15-2:45		396.50	
		Ventilation rate (V)	8:15-9:45		0.25	
			10:15-11:45		0.15	
			01:15-2:45		0.30	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	107	Temperature (T)	8:15-9:45		22.90	
			10:15-11:45		23.60	
			01:15-2:45		24.70	
		Humidity (H)	8:15-9:45		48	
			10:15-11:45		47	
			01:15-2:45		47	
		Co2 level(CO2)	8:15-9:45		947.16	
			10:15-11:45		916.45	
			01:15-2:45		1034.26	
		Noise level(N)	8:15-9:45		65.91	
			10:15-11:45		72.30	
			01:15-2:45		74.11	
		Lighting level (L)	8:15-9:45		494.30	
			10:15-11:45		462.20	
			01:15-2:45		540.00	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.28	
			01:15-2:45		0.15	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	106	Temperature (T)	8:15-9:45		23.60	
			10:15-11:45		24.50	
			01:15-2:45		23.60	
		Humidity (H)	8:15-9:45		49	
			10:15-11:45		45	
			01:15-2:45		51	
		Co2 level(CO2)	8:15-9:45		855.40	
			10:15-11:45		834.10	
			01:15-2:45		818.30	
		Noise level(N)	8:15-9:45		76.47	
			10:15-11:45		77.00	
			01:15-2:45		57.66	
		Lighting level (L)	8:15-9:45		405.30	
			10:15-11:45		524.10	
			01:15-2:45		534.60	
		Ventilation rate (V)	8:15-9:45		0.25	
			10:15-11:45		0.30	
			01:15-2:45		0.28	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	104	Temperature (T)	8:15-9:45		23.60	
			10:15-11:45		22.90	
			01:15-2:45		22.60	
		Humidity (H)	8:15-9:45		47	
			10:15-11:45		49	
			01:15-2:45		51	
		Co2 level(CO2)	8:15-9:45		686.56	
			10:15-11:45		682.20	
			01:15-2:45		678.60	
		Noise level(N)	8:15-9:45		75.00	
			10:15-11:45		63.55	
			01:15-2:45		62.35	
		Lighting level (L)	8:15-9:45		474.30	
			10:15-11:45		540.00	
			01:15-2:45		505.00	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.35	
			01:15-2:45		0.35	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	111	Temperature (T)	8:15-9:45		25.60	
			10:15-11:45		24.80	
			01:15-2:45		23.90	
		Humidity (H)	8:15-9:45		41	
			10:15-11:45		47	
			01:15-2:45		49	
		Co2 level(CO2)	8:15-9:45		854.70	
			10:15-11:45		846.80	
			01:15-2:45		868.55	
		Noise level(N)	8:15-9:45		72.12	
			10:15-11:45		67.60	
			01:15-2:45		58.80	
		Lighting level (L)	8:15-9:45		540.00	
			10:15-11:45		510.20	
			01:15-2:45		488.30	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.30	
			01:15-2:45		0.32	



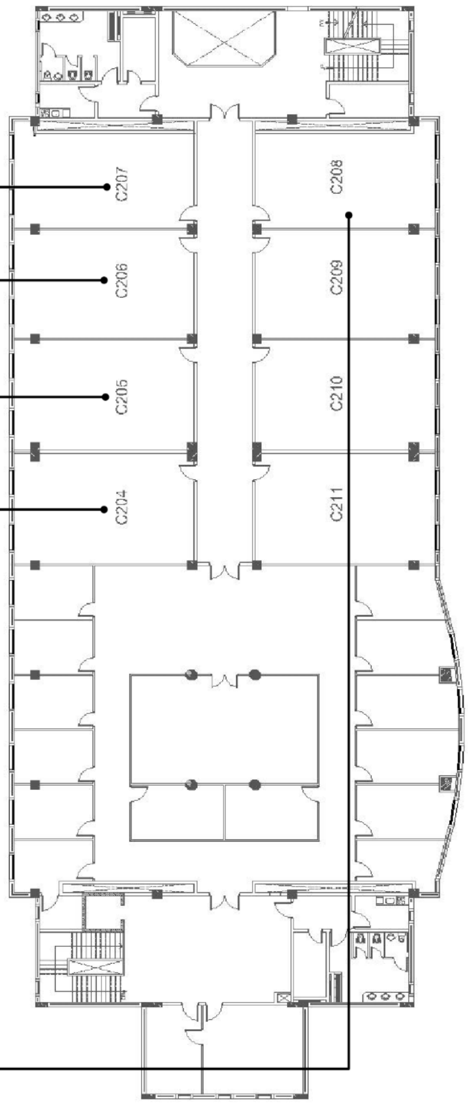
BLD code	CLS code	Variables	period	<	Recommended value	<
C	207	Temperature (T)	8:15-9:45		22.30	
			10:15-11:45		23.60	
			01:15-2:45		24.70	
		Humidity (H)	8:15-9:45		53	
			10:15-11:45		54	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		690.00	
			10:15-11:45		801.00	
			01:15-2:45		792.00	
		Noise level(N)	8:15-9:45		62.80	
			10:15-11:45		68.20	
			01:15-2:45		57.10	
		Lighting level (L)	8:15-9:45		302.00	
			10:15-11:45		332.00	
			01:15-2:45		341.00	
		Ventilation rate (V)	8:15-9:45		0.40	
			10:15-11:45		0.35	
			01:15-2:45		0.25	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	206	Temperature (T)	8:15-9:45		23.10	
			10:15-11:45		24.20	
			01:15-2:45		24.90	
		Humidity (H)	8:15-9:45		57	
			10:15-11:45		59	
			01:15-2:45		58	
		Co2 level(CO2)	8:15-9:45		732.00	
			10:15-11:45		756.00	
			01:15-2:45		731.00	
		Noise level(N)	8:15-9:45		72.30	
			10:15-11:45		51.90	
			01:15-2:45		57.40	
		Lighting level (L)	8:15-9:45		320.00	
			10:15-11:45		321.00	
			01:15-2:45		310.00	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.30	
			01:15-2:45		0.15	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	205	Temperature (T)	8:15-9:45		22.60	
			10:15-11:45		23.70	
			01:15-2:45		24.60	
		Humidity (H)	8:15-9:45		59	
			10:15-11:45		53	
			01:15-2:45		43	
		Co2 level(CO2)	8:15-9:45		783.00	
			10:15-11:45		772.00	
			01:15-2:45		656.00	
		Noise level(N)	8:15-9:45		51.50	
			10:15-11:45		71.20	
			01:15-2:45		62.30	
		Lighting level (L)	8:15-9:45		336.00	
			10:15-11:45		321.00	
			01:15-2:45		329.00	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.25	
			01:15-2:45		0.22	

BLD code	CLS code	Variables	period	<	Recommended value	<
C	204	Temperature (T)	8:15-9:45		22.30	
			10:15-11:45		24.10	
			01:15-2:45		25.60	
		Humidity (H)	8:15-9:45		51	
			10:15-11:45		50	
			01:15-2:45		53	
		Co2 level(CO2)	8:15-9:45		867.00	
			10:15-11:45		789.00	
			01:15-2:45		792.00	
		Noise level(N)	8:15-9:45		62.80	
			10:15-11:45		53.10	
			01:15-2:45		71.90	
		Lighting level (L)	8:15-9:45		362.00	
			10:15-11:45		351.00	
			01:15-2:45		373.00	
		Ventilation rate (V)	8:15-9:45		0.38	
			10:15-11:45		0.28	
			01:15-2:45		0.15	

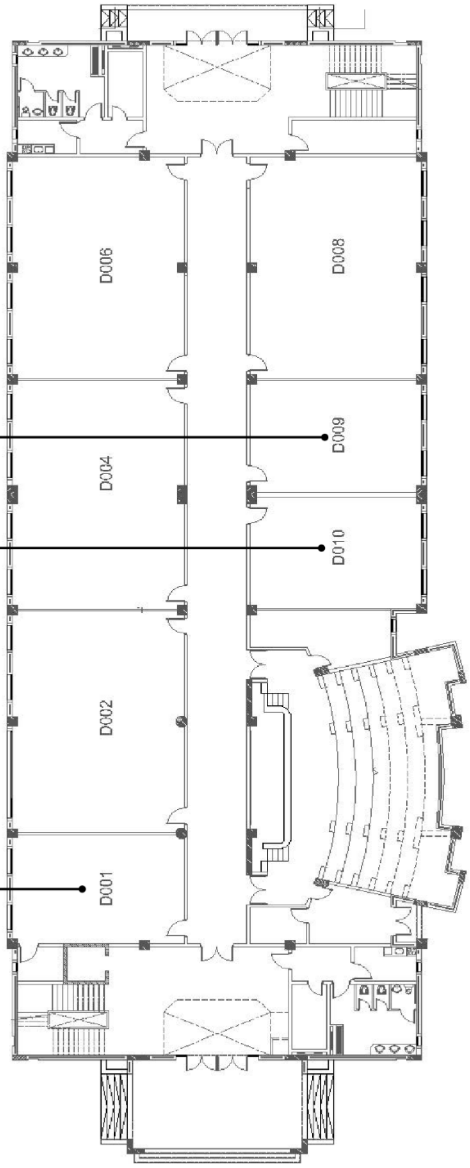
BLD code	CLS code	Variables	period	<	Recommended value	<
C	208	Temperature (T)	8:15-9:45		22.70	
			10:15-11:45		23.20	
			01:15-2:45		24.60	
		Humidity (H)	8:15-9:45		51	
			10:15-11:45		49	
			01:15-2:45		52	
		Co2 level(CO2)	8:15-9:45		780.00	
			10:15-11:45		862.00	
			01:15-2:45		851.00	
		Noise level(N)	8:15-9:45		69.60	
			10:15-11:45		71.20	
			01:15-2:45		52.40	
		Lighting level (L)	8:15-9:45		336.00	
			10:15-11:45		327.00	
			01:15-2:45		339.00	
		Ventilation rate (V)	8:15-9:45		0.40	
			10:15-11:45		0.30	
			01:15-2:45		0.30	



BLD code	CLS code	Variables	period	<	Recommended value	<
D	9	Temperature (T)	8:15-9:45		25.50	
			10:15-11:45		26.00	
			01:15-2:45		24.20	
		Humidity (H)	8:15-9:45		63	
			10:15-11:45		47	
			01:15-2:45		56	
		Co2 level(CO2)	8:15-9:45		806.00	
			10:15-11:45		815.00	
			01:15-2:45		826.00	
		Noise level(N)	8:15-9:45		60.00	
			10:15-11:45		59.00	
			01:15-2:45		58.00	
		Lighting level (L)	8:15-9:45		420.90	
			10:15-11:45		437.00	
			01:15-2:45		395.60	
		Ventilation rate (V)	8:15-9:45		0.25	
			10:15-11:45		0.15	
			01:15-2:45		0.35	

BLD code	CLS code	Variables	period	<	Recommended value	<
D	10	Temperature (T)	8:15-9:45		25.00	
			10:15-11:45		24.10	
			01:15-2:45		24.50	
		Humidity (H)	8:15-9:45		60	
			10:15-11:45		46	
			01:15-2:45		52	
		Co2 level(CO2)	8:15-9:45		860.00	
			10:15-11:45		867.00	
			01:15-2:45		867.00	
		Noise level(N)	8:15-9:45		55.00	
			10:15-11:45		53.00	
			01:15-2:45		54.00	
		Lighting level (L)	8:15-9:45		340.40	
			10:15-11:45		402.50	
			01:15-2:45		478.40	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.40	
			01:15-2:45		0.35	

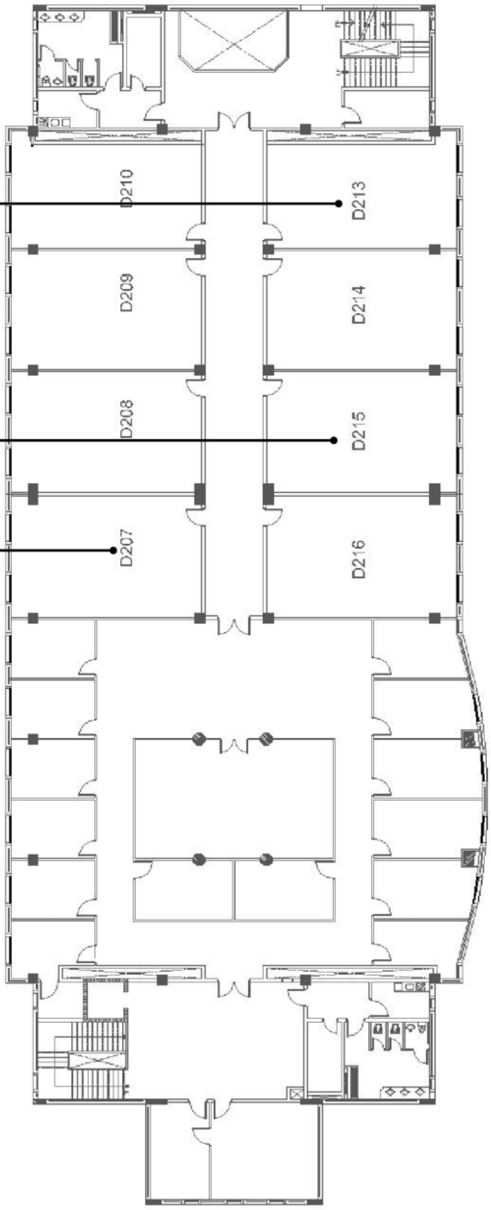
BLD code	CLS code	Variables	period	<	Recommended value	<
D	1	Temperature (T)	8:15-9:45		24.20	
			10:15-11:45		24.60	
			01:15-2:45		24.10	
		Humidity (H)	8:15-9:45		60	
			10:15-11:45		57	
			01:15-2:45		57	
		Co2 level(CO2)	8:15-9:45		623.00	
			10:15-11:45		634.00	
			01:15-2:45		642.00	
		Noise level(N)	8:15-9:45		72.00	
			10:15-11:45		59.50	
			01:15-2:45		60.00	
		Lighting level (L)	8:15-9:45		432.40	
			10:15-11:45		409.40	
			01:15-2:45		391.00	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.25	
			01:15-2:45		0.35	



BLD code	CLS code	Variables	period	<	Recommended value	<
D	213	Temperature (T)	8:15-9:45		24.50	
			10:15-11:45		25.90	
			01:15-2:45		25.00	
		Humidity (H)	8:15-9:45		59	
			10:15-11:45		48	
			01:15-2:45		59	
		Co2 level(CO2)	8:15-9:45		812.60	
			10:15-11:45		821.40	
			01:15-2:45		832.10	
		Noise level(N)	8:15-9:45		59.00	
			10:15-11:45		56.00	
			01:15-2:45		57.00	
		Lighting level (L)	8:15-9:45		426.30	
			10:15-11:45		448.00	
			01:15-2:45		405.00	
		Ventilation rate (V)	8:15-9:45		0.26	
			10:15-11:45		0.40	
			01:15-2:45		0.35	

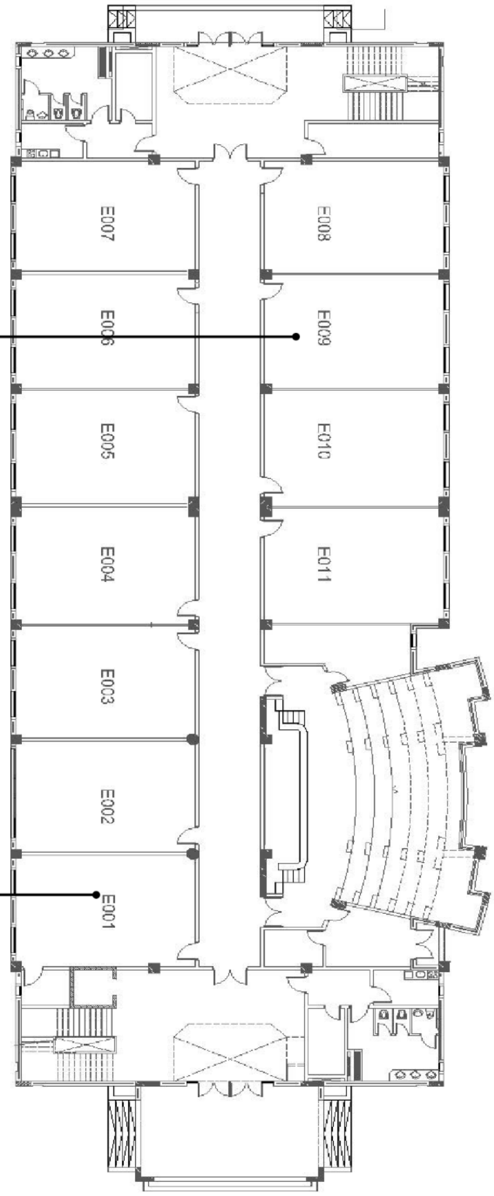
BLD code	CLS code	Variables	period	<	Recommended value	<
D	215	Temperature (T)	8:15-9:45		25.50	
			10:15-11:45		26.00	
			01:15-2:45		24.20	
		Humidity (H)	8:15-9:45		63	
			10:15-11:45		47	
			01:15-2:45		56	
		Co2 level(CO2)	8:15-9:45		806.00	
			10:15-11:45		815.20	
			01:15-2:45		826.50	
		Noise level(N)	8:15-9:45		60.00	
			10:15-11:45		59.00	
			01:15-2:45		58.00	
		Lighting level (L)	8:15-9:45		420.00	
			10:15-11:45		437.00	
			01:15-2:45		395.40	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.40	
			01:15-2:45		0.35	

BLD code	CLS code	Variables	period	<	Recommended value	<
D	207	Temperature (T)	8:15-9:45		26.50	
			10:15-11:45		25.00	
			01:15-2:45		26.00	
		Humidity (H)	8:15-9:45		53	
			10:15-11:45		40	
			01:15-2:45		37	
		Co2 level(CO2)	8:15-9:45		756.20	
			10:15-11:45		794.10	
			01:15-2:45		788.00	
		Noise level(N)	8:15-9:45		59.00	
			10:15-11:45		62.20	
			01:15-2:45		56.30	
		Lighting level (L)	8:15-9:45		407.20	
			10:15-11:45		376.00	
			01:15-2:45		419.10	
		Ventilation rate (V)	8:15-9:45		0.18	
			10:15-11:45		0.25	
			01:15-2:45		0.22	



BLD code	CLS code	Variables	period	<	Recommended value	<
E	10	Temperature (T)	8:15-9:45		24.00	
			10:15-11:45		22.70	
			01:15-2:45		22.50	
		Humidity (H)	8:15-9:45		40	
			10:15-11:45		49	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		1073.10	
			10:15-11:45		1010.40	
			01:15-2:45		980.20	
		Noise level(N)	8:15-9:45		61.70	
			10:15-11:45		54.20	
			01:15-2:45		57.00	
		Lighting level (L)	8:15-9:45		431.70	
			10:15-11:45		441.60	
			01:15-2:45		441.70	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.32	
			01:15-2:45		0.30	

BLD code	CLS code	Variables	period	<	Recommended value	<
E	1	Temperature (T)	8:15-9:45		24.30	
			10:15-11:45		23.80	
			01:15-2:45		23.20	
		Humidity (H)	8:15-9:45		50	
			10:15-11:45		52	
			01:15-2:45		53	
		Co2 level(CO2)	8:15-9:45		1210.30	
			10:15-11:45		1190.70	
			01:15-2:45		1120.80	
		Noise level(N)	8:15-9:45		62.00	
			10:15-11:45		61.00	
			01:15-2:45		56.00	
		Lighting level (L)	8:15-9:45		501.40	
			10:15-11:45		465.60	
			01:15-2:45		495.40	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.30	
			01:15-2:45		0.28	

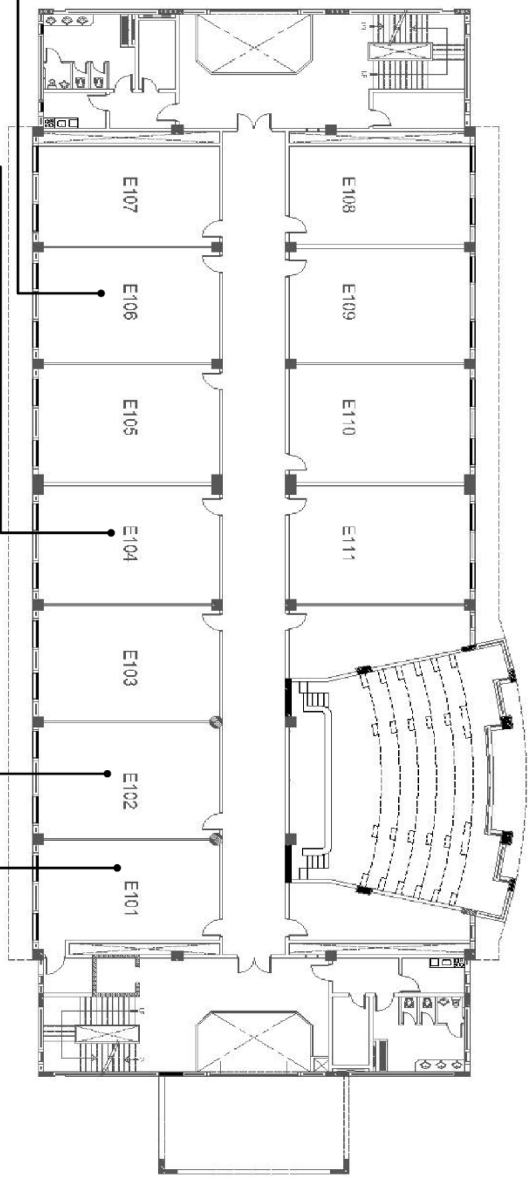


BLD code	CLS code	Variables	period	<	Recommended value	<
E	106	Temperature (T)	8:15-9:45		23.00	
			10:15-11:45		24.10	
			01:15-2:45		24.20	
		Humidity (H)	8:15-9:45		51	
			10:15-11:45		50	
			01:15-2:45		47	
		Co2 level(CO2)	8:15-9:45		886.00	
			10:15-11:45		901.00	
			01:15-2:45		920.20	
		Noise level(N)	8:15-9:45		56.60	
			10:15-11:45		65.00	
			01:15-2:45		51.00	
		Lighting level (L)	8:15-9:45		487.50	
			10:15-11:45		492.20	
			01:15-2:45		411.70	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.25	
			01:15-2:45		0.25	

BLD code	CLS code	Variables	period	<	Recommended value	<
E	104	Temperature (T)	8:15-9:45		25.10	
			10:15-11:45		24.20	
			01:15-2:45		24.00	
		Humidity (H)	8:15-9:45		50	
			10:15-11:45		54	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		763.50	
			10:15-11:45		776.40	
			01:15-2:45		780.10	
		Noise level(N)	8:15-9:45		61.00	
			10:15-11:45		65.00	
			01:15-2:45		55.00	
		Lighting level (L)	8:15-9:45		466.80	
			10:15-11:45		483.00	
			01:15-2:45		415.20	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.35	
			01:15-2:45		0.30	

BLD code	CLS code	Variables	period	<	Recommended value	<
E	102	Temperature (T)	8:15-9:45		24.30	
			10:15-11:45		24.70	
			01:15-2:45		24.50	
		Humidity (H)	8:15-9:45		51	
			10:15-11:45		55	
			01:15-2:45		49	
		Co2 level(CO2)	8:15-9:45		809.20	
			10:15-11:45		821.10	
			01:15-2:45		829.80	
		Noise level(N)	8:15-9:45		55.10	
			10:15-11:45		61.00	
			01:15-2:45		57.00	
		Lighting level (L)	8:15-9:45		512.20	
			10:15-11:45		517.20	
			01:15-2:45		540.00	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.28	
			01:15-2:45		0.25	

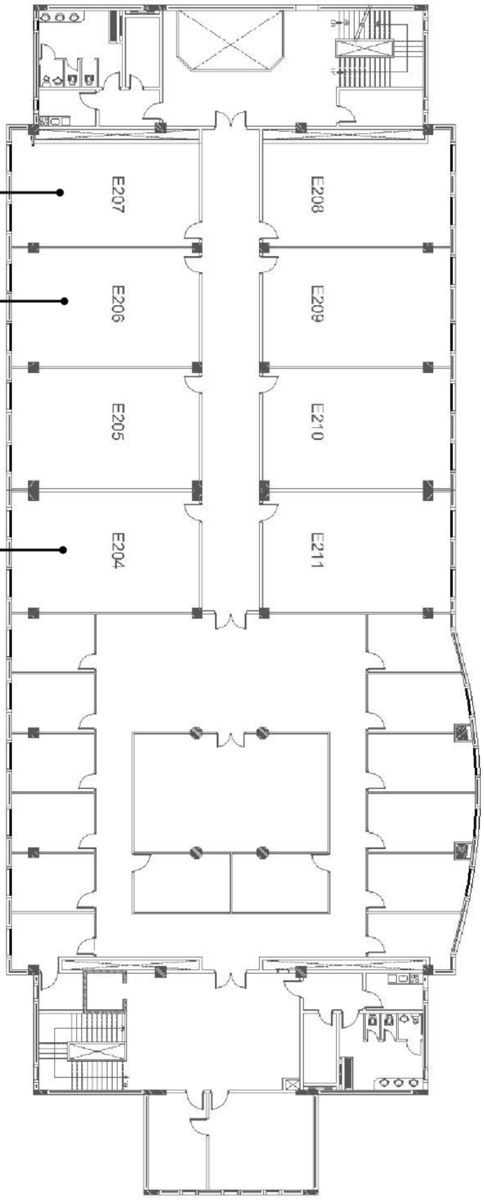
BLD code	CLS code	Variables	period	<	Recommended value	<
E	101	Temperature (T)	8:15-9:45		26.10	
			10:15-11:45		24.30	
			01:15-2:45		26.50	
		Humidity (H)	8:15-9:45		47	
			10:15-11:45		51	
			01:15-2:45		49	
		Co2 level(CO2)	8:15-9:45		1092.20	
			10:15-11:45		1103.50	
			01:15-2:45		1117.20	
		Noise level(N)	8:15-9:45		62.50	
			10:15-11:45		55.00	
			01:15-2:45		61.00	
		Lighting level (L)	8:15-9:45		492.50	
			10:15-11:45		540.00	
			01:15-2:45		460.00	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.32	
			01:15-2:45		0.15	



BLD code	CLS code	Variables	period	<	Recommended value	<
E	207	Temperature (T)	8:15-9:45		23.00	
			10:15-11:45		24.10	
			01:15-2:45		24.20	
		Humidity (H)	8:15-9:45		51	
			10:15-11:45		50	
			01:15-2:45		47	
		Co2 level(CO2)	8:15-9:45		886.00	
			10:15-11:45		901.00	
			01:15-2:45		920.00	
		Noise level(N)	8:15-9:45		52.00	
			10:15-11:45		65.00	
			01:15-2:45		51.00	
		Lighting level (L)	8:15-9:45		487.60	
			10:15-11:45		492.20	
			01:15-2:45		411.70	
		Ventilation rate (V)	8:15-9:45		0.30	
			10:15-11:45		0.20	
			01:15-2:45		0.25	

BLD code	CLS code	Variables	period	<	Recommended value	<
E	206	Temperature (T)	8:15-9:45		24.00	
			10:15-11:45		22.70	
			01:15-2:45		22.50	
		Humidity (H)	8:15-9:45		40	
			10:15-11:45		49	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		1073.00	
			10:15-11:45		1010.00	
			01:15-2:45		980.00	
		Noise level(N)	8:15-9:45		61.70	
			10:15-11:45		54.20	
			01:15-2:45		57.00	
		Lighting level (L)	8:15-9:45		431.71	
			10:15-11:45		441.60	
			01:15-2:45		411.70	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.32	
			01:15-2:45		0.30	

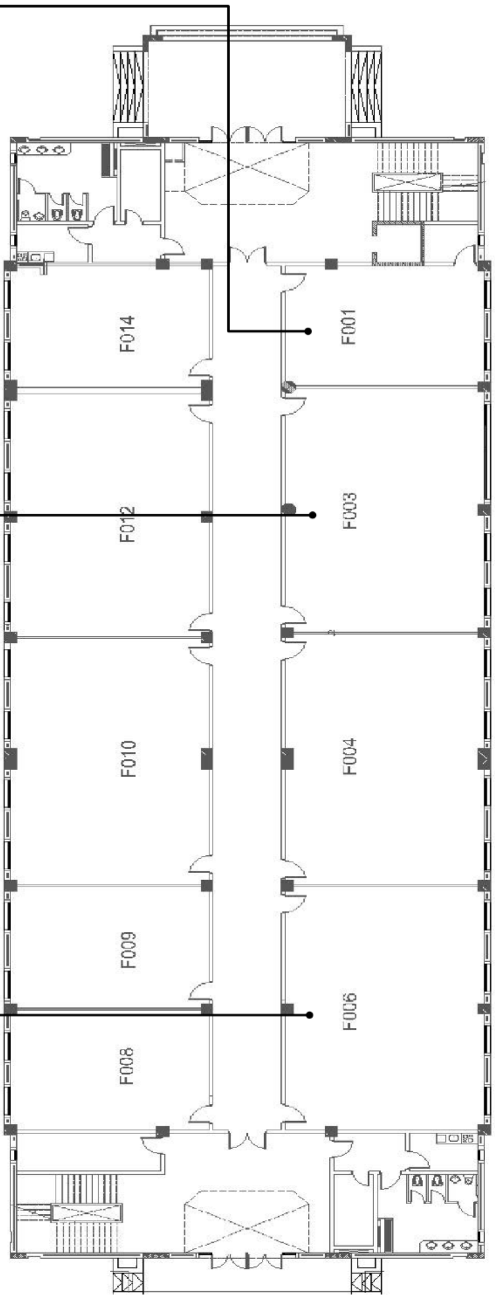
BLD code	CLS code	Variables	period	<	Recommended value	<
E	204	Temperature (T)	8:15-9:45		25.00	
			10:15-11:45		24.20	
			01:15-2:45		25.10	
		Humidity (H)	8:15-9:45		50	
			10:15-11:45		54	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		763.00	
			10:15-11:45		776.00	
			01:15-2:45		780.00	
		Noise level(N)	8:15-9:45		61.00	
			10:15-11:45		65.00	
			01:15-2:45		55.00	
		Lighting level (L)	8:15-9:45		466.90	
			10:15-11:45		483.00	
			01:15-2:45		415.15	
		Ventilation rate (V)	8:15-9:45		0.28	
			10:15-11:45		0.20	
			01:15-2:45		0.25	



BLD code	CLS code	Variables	period	< Recommended value <
F	1	Temperature (T)	8:15-9:45	26.10
			10:15-11:45	22.20
			01:15-2:45	23.00
		Humidity (H)	8:15-9:45	51
			10:15-11:45	50
			01:15-2:45	48
		Co2 level(CO2)	8:15-9:45	813.30
			10:15-11:45	820.20
			01:15-2:45	835.10
		Noise level(N)	8:15-9:45	58.00
			10:15-11:45	55.40
			01:15-2:45	52.00
		Lighting level (L)	8:15-9:45	356.00
			10:15-11:45	460.00
			01:15-2:45	440.20
		Ventilation rate (V)	8:15-9:45	0.15
			10:15-11:45	0.38
			01:15-2:45	0.30

BLD code	CLS code	Variables	period	< Recommended value <
F	9	Temperature (T)	8:15-9:45	24.20
			10:15-11:45	26.90
			01:15-2:45	24.60
		Humidity (H)	8:15-9:45	71
			10:15-11:45	46
			01:15-2:45	55
		Co2 level(CO2)	8:15-9:45	682.30
			10:15-11:45	670.00
			01:15-2:45	693.00
		Noise level(N)	8:15-9:45	56.00
			10:15-11:45	49.00
			01:15-2:45	52.00
		Lighting level (L)	8:15-9:45	348.40
			10:15-11:45	379.50
			01:15-2:45	303.60
		Ventilation rate (V)	8:15-9:45	0.20
			10:15-11:45	0.15
			01:15-2:45	0.25

BLD code	CLS code	Variables	period	< Recommended value <
F	6	Temperature (T)	8:15-9:45	25.10
			10:15-11:45	23.10
			01:15-2:45	25.00
		Humidity (H)	8:15-9:45	47
			10:15-11:45	53
			01:15-2:45	48
		Co2 level(CO2)	8:15-9:45	714.90
			10:15-11:45	706.20
			01:15-2:45	700.70
		Noise level(N)	8:15-9:45	57.00
			10:15-11:45	57.50
			01:15-2:45	58.60
		Lighting level (L)	8:15-9:45	437.00
			10:15-11:45	460.00
			01:15-2:45	437.00
		Ventilation rate (V)	8:15-9:45	0.20
			10:15-11:45	0.32
			01:15-2:45	0.15

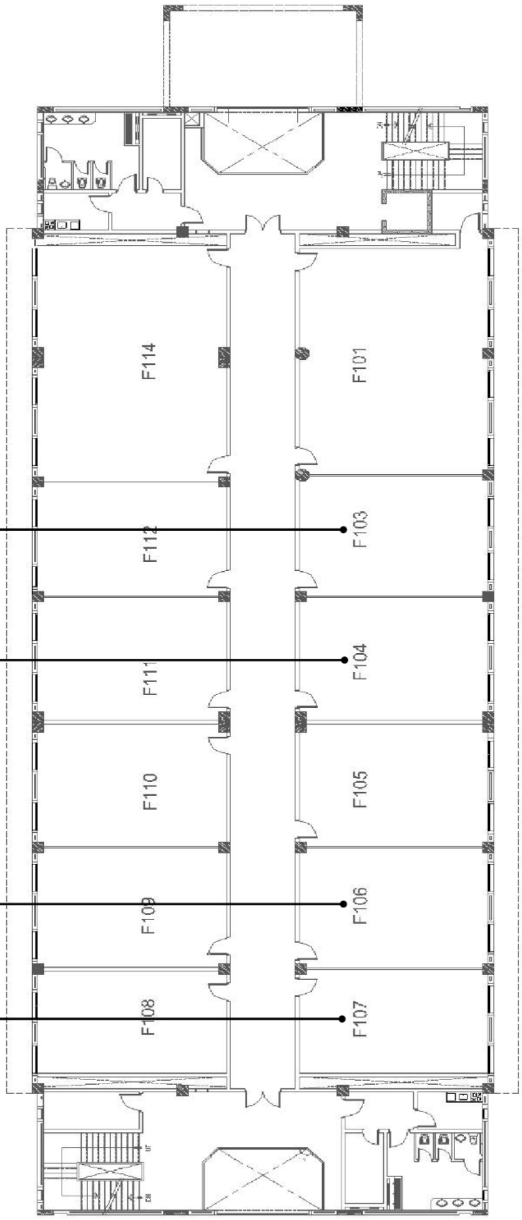


BLD code	CLS code	Variables	period	<	Recommended value	<
F	103	Temperature (T)	8:15-9:45		24.00	
			10:15-11:45		25.80	
			01:15-2:45		23.50	
		Humidity (H)	8:15-9:45		48	
			10:15-11:45		46	
			01:15-2:45		53	
		Co2 level(CO2)	8:15-9:45		760.70	
			10:15-11:45		783.80	
			01:15-2:45		786.40	
		Noise level(N)	8:15-9:45		48.00	
			10:15-11:45		47.00	
			01:15-2:45		50.00	
		Lighting level (L)	8:15-9:45		385.00	
			10:15-11:45		540.00	
			01:15-2:45		457.20	
		Ventilation rate (V)	8:15-9:45		0.22	
			10:15-11:45		0.18	
			01:15-2:45		0.30	

BLD code	CLS code	Variables	period	<	Recommended value	<
F	104	Temperature (T)	8:15-9:45		24.10	
			10:15-11:45		23.20	
			01:15-2:45		23.00	
		Humidity (H)	8:15-9:45		48	
			10:15-11:45		50	
			01:15-2:45		52	
		Co2 level(CO2)	8:15-9:45		696.70	
			10:15-11:45		691.10	
			01:15-2:45		687.00	
		Noise level(N)	8:15-9:45		48.20	
			10:15-11:45		53.00	
			01:15-2:45		52.00	
		Lighting level (L)	8:15-9:45		451.60	
			10:15-11:45		535.80	
			01:15-2:45		483.20	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.32	
			01:15-2:45		0.30	

BLD code	CLS code	Variables	period	<	Recommended value	<
F	106	Temperature (T)	8:15-9:45		23.70	
			10:15-11:45		24.90	
			01:15-2:45		24.10	
		Humidity (H)	8:15-9:45		50	
			10:15-11:45		46	
			01:15-2:45		52	
		Co2 level(CO2)	8:15-9:45		687.10	
			10:15-11:45		845.30	
			01:15-2:45		829.40	
		Noise level(N)	8:15-9:45		64.00	
			10:15-11:45		65.00	
			01:15-2:45		48.00	
		Lighting level (L)	8:15-9:45		386.00	
			10:15-11:45		494.00	
			01:15-2:45		530.30	
		Ventilation rate (V)	8:15-9:45		0.35	
			10:15-11:45		0.20	
			01:15-2:45		0.30	

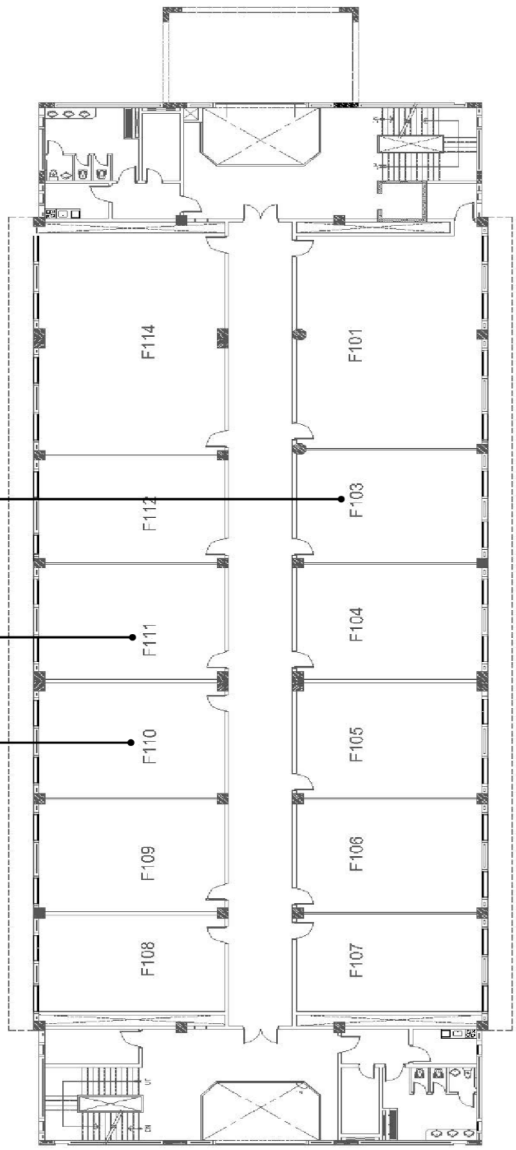
BLD code	CLS code	Variables	period	<	Recommended value	<
F	107	Temperature (T)	8:15-9:45		23.20	
			10:15-11:45		24.10	
			01:15-2:45		25.20	
		Humidity (H)	8:15-9:45		49	
			10:15-11:45		48	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		960.50	
			10:15-11:45		929.30	
			01:15-2:45		1057.00	
		Noise level(N)	8:15-9:45		55.00	
			10:15-11:45		65.00	
			01:15-2:45		62.00	
		Lighting level (L)	8:15-9:45		379.50	
			10:15-11:45		453.30	
			01:15-2:45		422.00	
		Ventilation rate (V)	8:15-9:45		0.32	
			10:15-11:45		0.30	
			01:15-2:45		0.20	



BLD code	CLS code	Variables	period	<	Recommended value	<
F	103	Temperature (T)	8:15-9:45		24.10	
			10:15-11:45		23.20	
			01:15-2:45		23.00	
		Humidity (H)	8:15-9:45		48	
			10:15-11:45		50	
			01:15-2:45		52	
		Co2 level(CO2)	8:15-9:45		696.00	
			10:15-11:45		691.00	
			01:15-2:45		687.00	
		Noise level(N)	8:15-9:45		50.30	
			10:15-11:45		53.00	
			01:15-2:45		52.00	
		Lighting level (L)	8:15-9:45		451.72	
			10:15-11:45		525.78	
			01:15-2:45		483.00	
		Ventilation rate (V)	8:15-9:45		0.20	
			10:15-11:45		0.32	
			01:15-2:45		0.28	

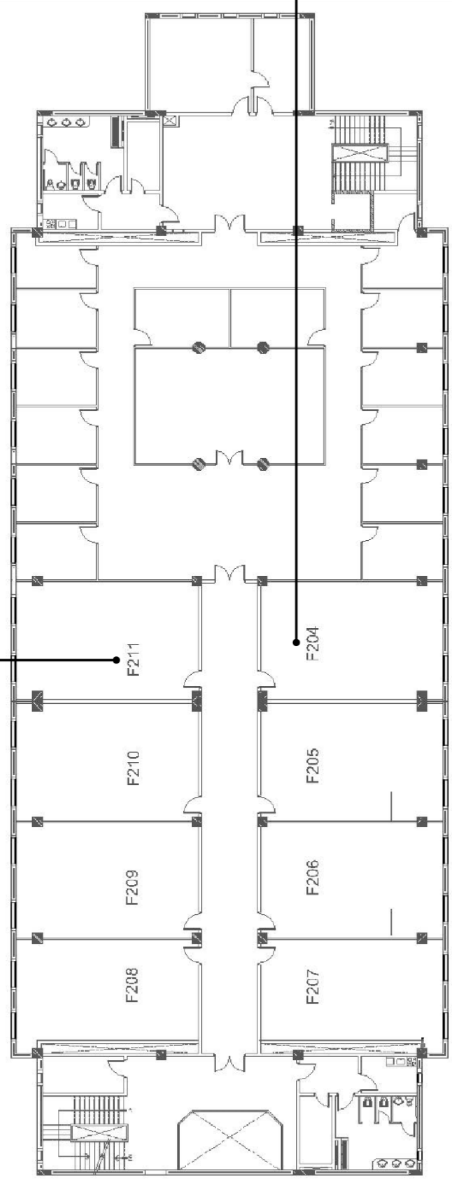
BLD code	CLS code	Variables	period	<	Recommended value	<
F	111	Temperature (T)	8:15-9:45		23.50	
			10:15-11:45		24.20	
			01:15-2:45		25.20	
		Humidity (H)	8:15-9:45		49	
			10:15-11:45		48	
			01:15-2:45		48	
		Co2 level(CO2)	8:15-9:45		960.00	
			10:15-11:45		929.00	
			01:15-2:45		1057.00	
		Noise level(N)	8:15-9:45		55.00	
			10:15-11:45		65.00	
			01:15-2:45		62.00	
		Lighting level (L)	8:15-9:45		379.50	
			10:15-11:45		453.10	
			01:15-2:45		609.50	
		Ventilation rate (V)	8:15-9:45		0.28	
			10:15-11:45		0.30	
			01:15-2:45		0.20	

BLD code	CLS code	Variables	period	<	Recommended value	<
F	110	Temperature (T)	8:15-9:45		24.20	
			10:15-11:45		25.60	
			01:15-2:45		23.70	
		Humidity (H)	8:15-9:45		48	
			10:15-11:45		46	
			01:15-2:45		53	
		Co2 level(CO2)	8:15-9:45		760.00	
			10:15-11:45		783.00	
			01:15-2:45		786.00	
		Noise level(N)	8:15-9:45		48.00	
			10:15-11:45		47.00	
			01:15-2:45		50.00	
		Lighting level (L)	8:15-9:45		385.25	
			10:15-11:45		540.50	
			01:15-2:45		457.70	
		Ventilation rate (V)	8:15-9:45		0.25	
			10:15-11:45		0.20	
			01:15-2:45		0.32	



BLD code	CLS code	Variables	period	< Recommended value <
F	204	Temperature (T)	8:15-9:45	24.50
			10:15-11:45	23.70
			01:15-2:45	23.50
		Humidity (H)	8:15-9:45	48
			10:15-11:45	50
			01:15-2:45	52
		Co2 level(CO2)	8:15-9:45	696.00
			10:15-11:45	691.00
			01:15-2:45	687.00
		Noise level(N)	8:15-9:45	50.20
			10:15-11:45	51.50
			01:15-2:45	50.00
		Lighting level (L)	8:15-9:45	451.72
			10:15-11:45	525.78
			01:15-2:45	483.00
		Ventilation rate (V)	8:15-9:45	0.20
			10:15-11:45	0.32
			01:15-2:45	0.30

BLD code	CLS code	Variables	period	< Recommended value <
F	211	Temperature (T)	8:15-9:45	24.20
			10:15-11:45	26.90
			01:15-2:45	24.60
		Humidity (H)	8:15-9:45	71
			10:15-11:45	46
			01:15-2:45	55
		Co2 level(CO2)	8:15-9:45	682.00
			10:15-11:45	670.00
			01:15-2:45	693.00
		Noise level(N)	8:15-9:45	56.00
			10:15-11:45	49.00
			01:15-2:45	52.00
		Lighting level (L)	8:15-9:45	356.50
			10:15-11:45	379.50
			01:15-2:45	303.60
		Ventilation rate (V)	8:15-9:45	0.25
			10:15-11:45	0.15
			01:15-2:45	0.20

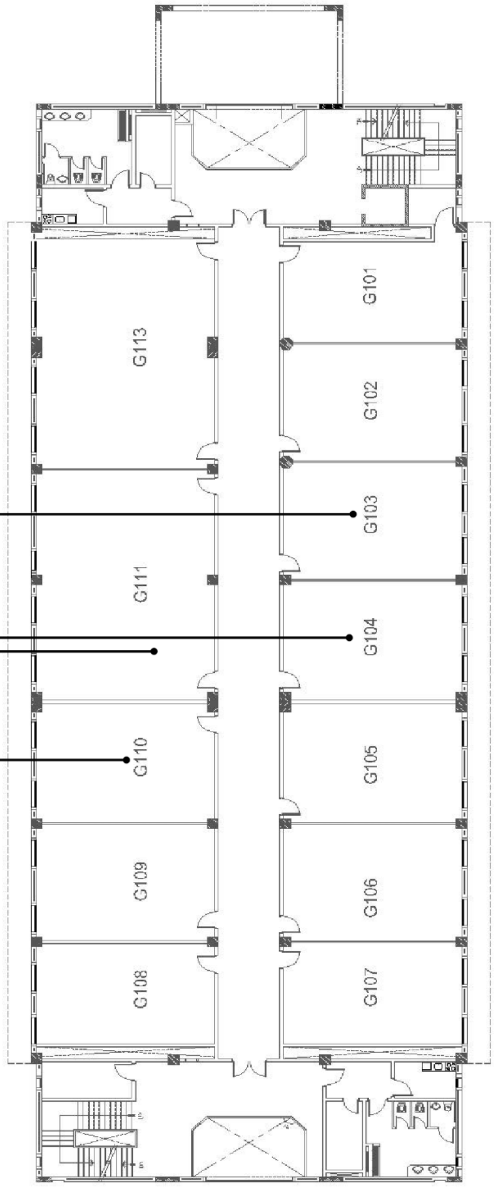


BLD code	CLS code	Variables	period	< Recommended value <
G	103	Temperature (T)	8:15-9:45	22.00
			10:15-11:45	23.60
			01:15-2:45	22.10
		Humidity (H)	8:15-9:45	53
			10:15-11:45	42
			01:15-2:45	48
		Co2 level(CO2)	8:15-9:45	783.45
			10:15-11:45	807.60
			01:15-2:45	810.20
		Noise level(N)	8:15-9:45	48.78
			10:15-11:45	47.00
			01:15-2:45	50.65
		Lighting level (L)	8:15-9:45	286.70
			10:15-11:45	349.80
			01:15-2:45	396.40
		Ventilation rate (V)	8:15-9:45	0.35
			10:15-11:45	0.30
			01:15-2:45	0.35

BLD code	CLS code	Variables	period	< Recommended value <
G	104	Temperature (T)	8:15-9:45	22.50
			10:15-11:45	22.10
			01:15-2:45	21.80
		Humidity (H)	8:15-9:45	42
			10:15-11:45	43
			01:15-2:45	47
		Co2 level(CO2)	8:15-9:45	752.56
			10:15-11:45	761.60
			01:15-2:45	773.30
		Noise level(N)	8:15-9:45	56.80
			10:15-11:45	51.40
			01:15-2:45	51.70
		Lighting level (L)	8:15-9:45	318.50
			10:15-11:45	332.90
			01:15-2:45	400.50
		Ventilation rate (V)	8:15-9:45	0.30
			10:15-11:45	0.35
			01:15-2:45	0.35

BLD code	CLS code	Variables	period	< Recommended value <
G	111	Temperature (T)	8:15-9:45	24.00
			10:15-11:45	22.50
			01:15-2:45	22.80
		Humidity (H)	8:15-9:45	38
			10:15-11:45	44
			01:15-2:45	45
		Co2 level(CO2)	8:15-9:45	892.05
			10:15-11:45	903.10
			01:15-2:45	907.20
		Noise level(N)	8:15-9:45	62.45
			10:15-11:45	56.30
			01:15-2:45	49.86
		Lighting level (L)	8:15-9:45	301.40
			10:15-11:45	317.70
			01:15-2:45	327.80
		Ventilation rate (V)	8:15-9:45	0.20
			10:15-11:45	0.35
			01:15-2:45	0.30

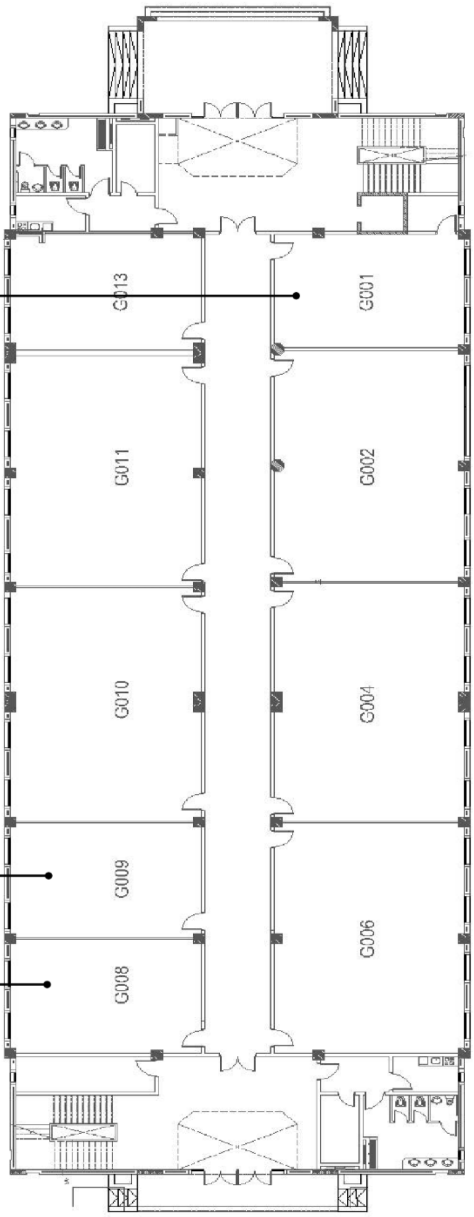
BLD code	CLS code	Variables	period	< Recommended value <
G	110	Temperature (T)	8:15-9:45	23.00
			10:15-11:45	23.80
			01:15-2:45	22.10
		Humidity (H)	8:15-9:45	41
			10:15-11:45	40
			01:15-2:45	44
		Co2 level(CO2)	8:15-9:45	88.60
			10:15-11:45	911.20
			01:15-2:45	892.50
		Noise level(N)	8:15-9:45	53.12
			10:15-11:45	62.15
			01:15-2:45	49.11
		Lighting level (L)	8:15-9:45	285.00
			10:15-11:45	300.80
			01:15-2:45	266.40
		Ventilation rate (V)	8:15-9:45	0.32
			10:15-11:45	0.20
			01:15-2:45	0.35



BLD code	CLS code	Variables	period	< Recommended value <
G	1	Temperature (T)	8:15-9:45	23.00
			10:15-11:45	23.60
			01:15-2:45	22.10
		Humidity (H)	8:15-9:45	43
			10:15-11:45	52
			01:15-2:45	60
		Co2 level(CO2)	8:15-9:45	783.51
			10:15-11:45	807.22
			01:15-2:45	810.31
		Noise level(N)	8:15-9:45	49.48
			10:15-11:45	48.45
			01:15-2:45	51.55
		Lighting level (L)	8:15-9:45	414.25
			10:15-11:45	581.18
			01:15-2:45	492.15
		Ventilation rate (V)	8:15-9:45	0.30
			10:15-11:45	0.28
			01:15-2:45	0.30

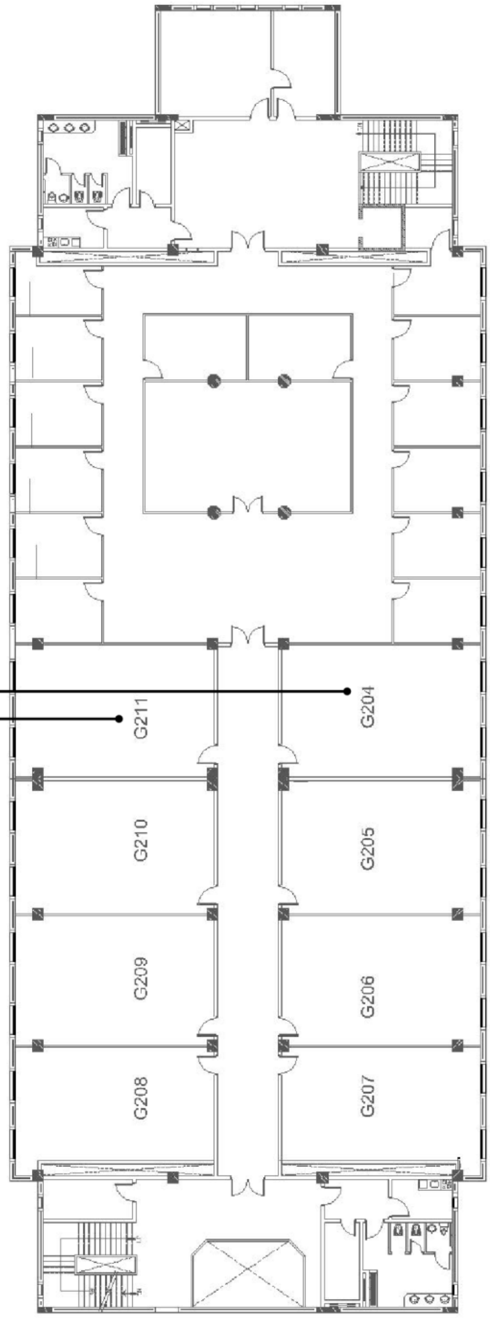
BLD code	CLS code	Variables	period	< Recommended value <
G	9	Temperature (T)	8:15-9:45	24.00
			10:15-11:45	23.00
			01:15-2:45	22.60
		Humidity (H)	8:15-9:45	47
			10:15-11:45	54
			01:15-2:45	56
		Co2 level(CO2)	8:15-9:45	892.78
			10:15-11:45	903.09
			01:15-2:45	907.22
		Noise level(N)	8:15-9:45	63.92
			10:15-11:45	57.73
			01:15-2:45	50.52
		Lighting level (L)	8:15-9:45	556.45
			10:15-11:45	519.35
			01:15-2:45	499.57
		Ventilation rate (V)	8:15-9:45	0.20
			10:15-11:45	0.30
			01:15-2:45	0.30

BLD code	CLS code	Variables	period	< Recommended value <
G	8	Temperature (T)	8:15-9:45	23.00
			10:15-11:45	23.80
			01:15-2:45	22.10
		Humidity (H)	8:15-9:45	51
			10:15-11:45	51
			01:15-2:45	54
		Co2 level(CO2)	8:15-9:45	886.60
			10:15-11:45	900.00
			01:15-2:45	893.81
		Noise level(N)	8:15-9:45	54.64
			10:15-11:45	63.92
			01:15-2:45	50.52
		Lighting level (L)	8:15-9:45	457.53
			10:15-11:45	442.69
			01:15-2:45	405.59
		Ventilation rate (V)	8:15-9:45	0.35
			10:15-11:45	0.30
			01:15-2:45	0.38



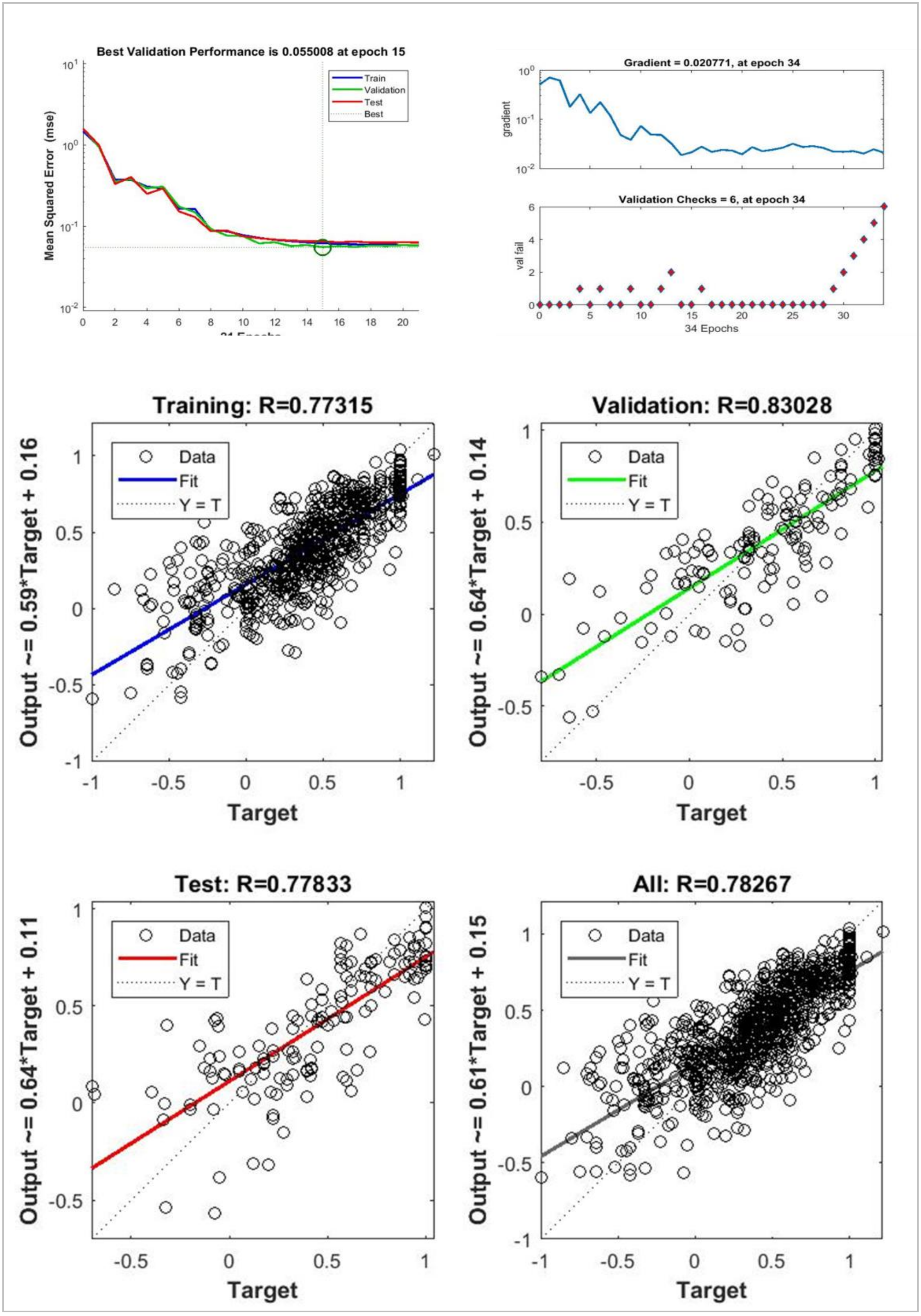
BLD code	CLS code	Variables	period	< Recommended value <
G	204	Temperature (T)	8:15-9:45	22.20
			10:15-11:45	21.90
			01:15-2:45	22.10
		Humidity (H)	8:15-9:45	52
			10:15-11:45	53
			01:15-2:45	58
		Co2 level(CO2)	8:15-9:45	752.58
			10:15-11:45	761.86
			01:15-2:45	773.20
		Noise level(N)	8:15-9:45	52.37
			10:15-11:45	52.89
			01:15-2:45	52.06
		Lighting level (L)	8:15-9:45	432.55
			10:15-11:45	482.26
			01:15-2:45	581.18
		Ventilation rate (V)	8:15-9:45	0.38
			10:15-11:45	0.40
			01:15-2:45	0.40

BLD code	CLS code	Variables	period	< Recommended value <
G	211	Temperature (T)	8:15-9:45	24.00
			10:15-11:45	23.10
			01:15-2:45	22.60
		Humidity (H)	8:15-9:45	47
			10:15-11:45	54
			01:15-2:45	56
		Co2 level(CO2)	8:15-9:45	892.78
			10:15-11:45	903.09
			01:15-2:45	907.22
		Noise level(N)	8:15-9:45	63.92
			10:15-11:45	57.73
			01:15-2:45	50.52
		Lighting level (L)	8:15-9:45	556.45
			10:15-11:45	519.35
			01:15-2:45	499.57
		Ventilation rate (V)	8:15-9:45	0.20
			10:15-11:45	0.30
			01:15-2:45	0.30

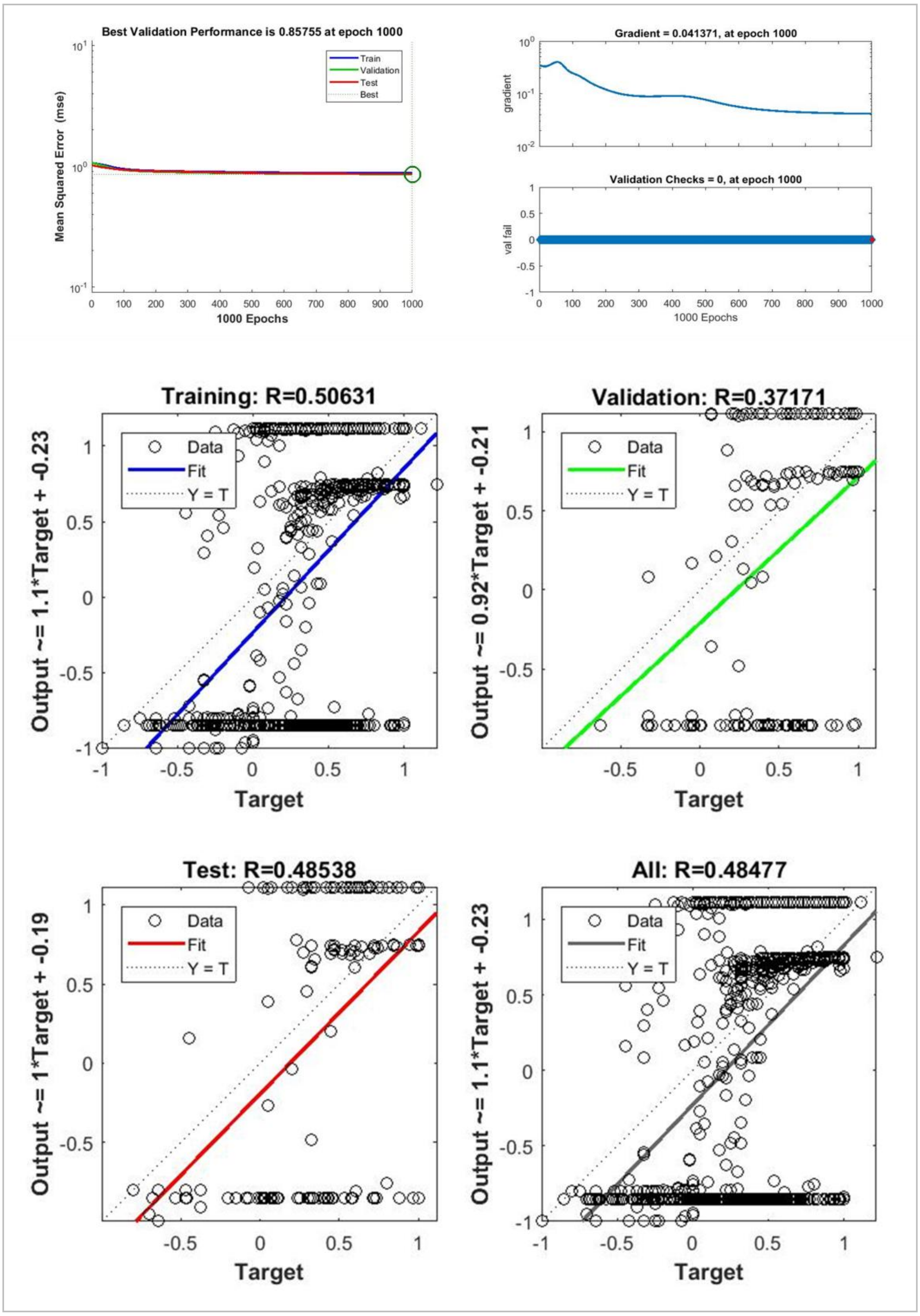


The results of algorithm training

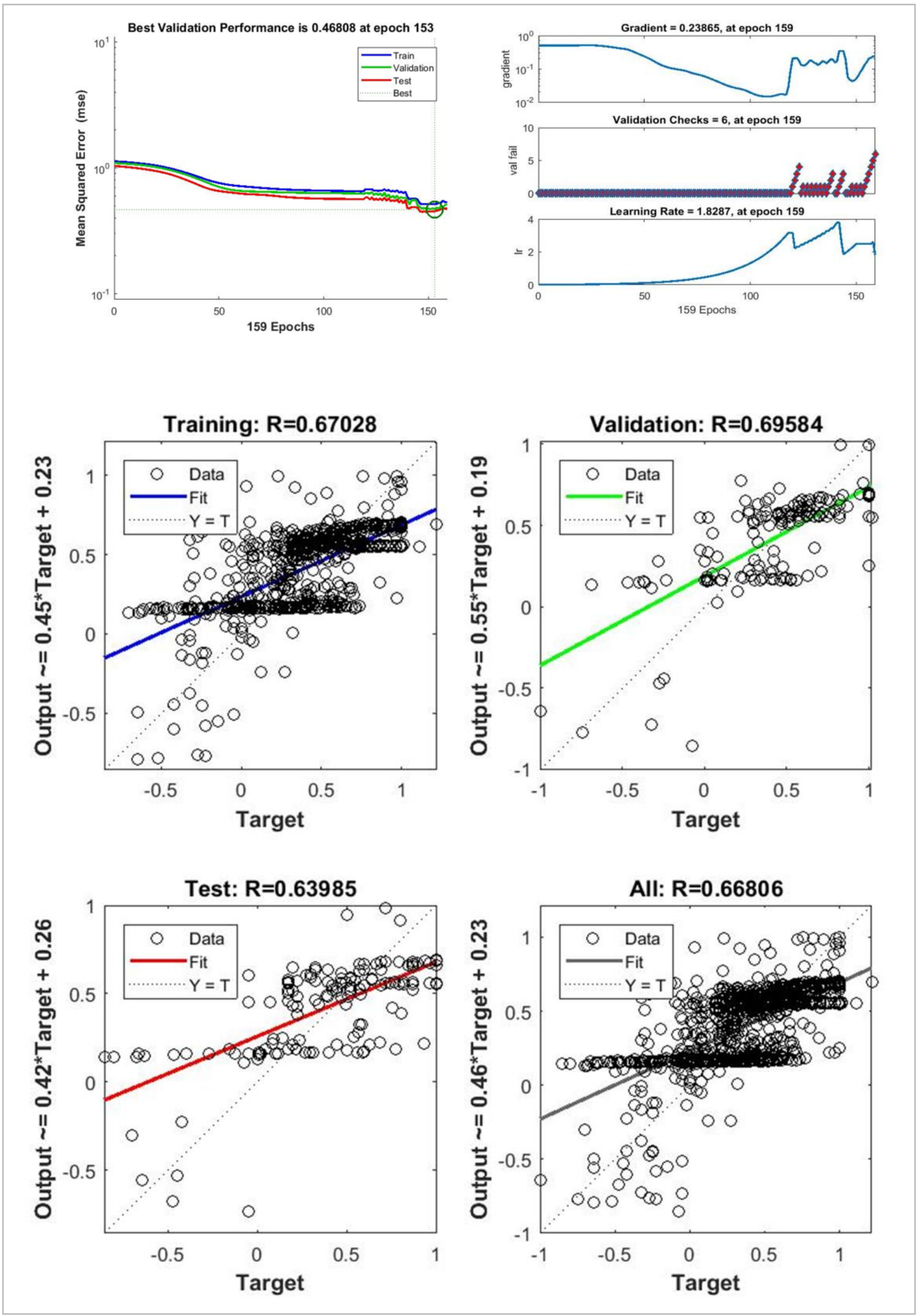
Train RP model



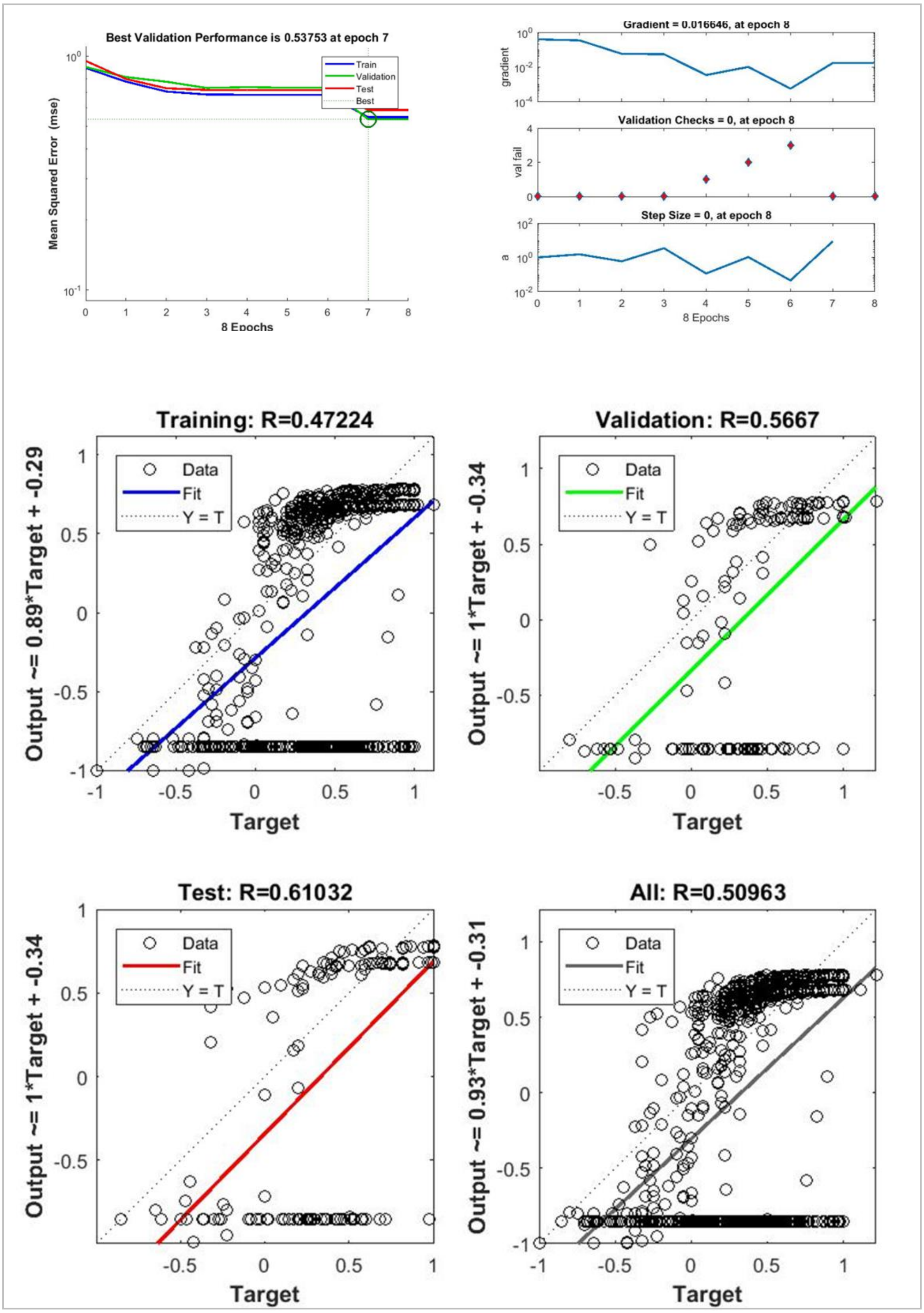
Train GDM model



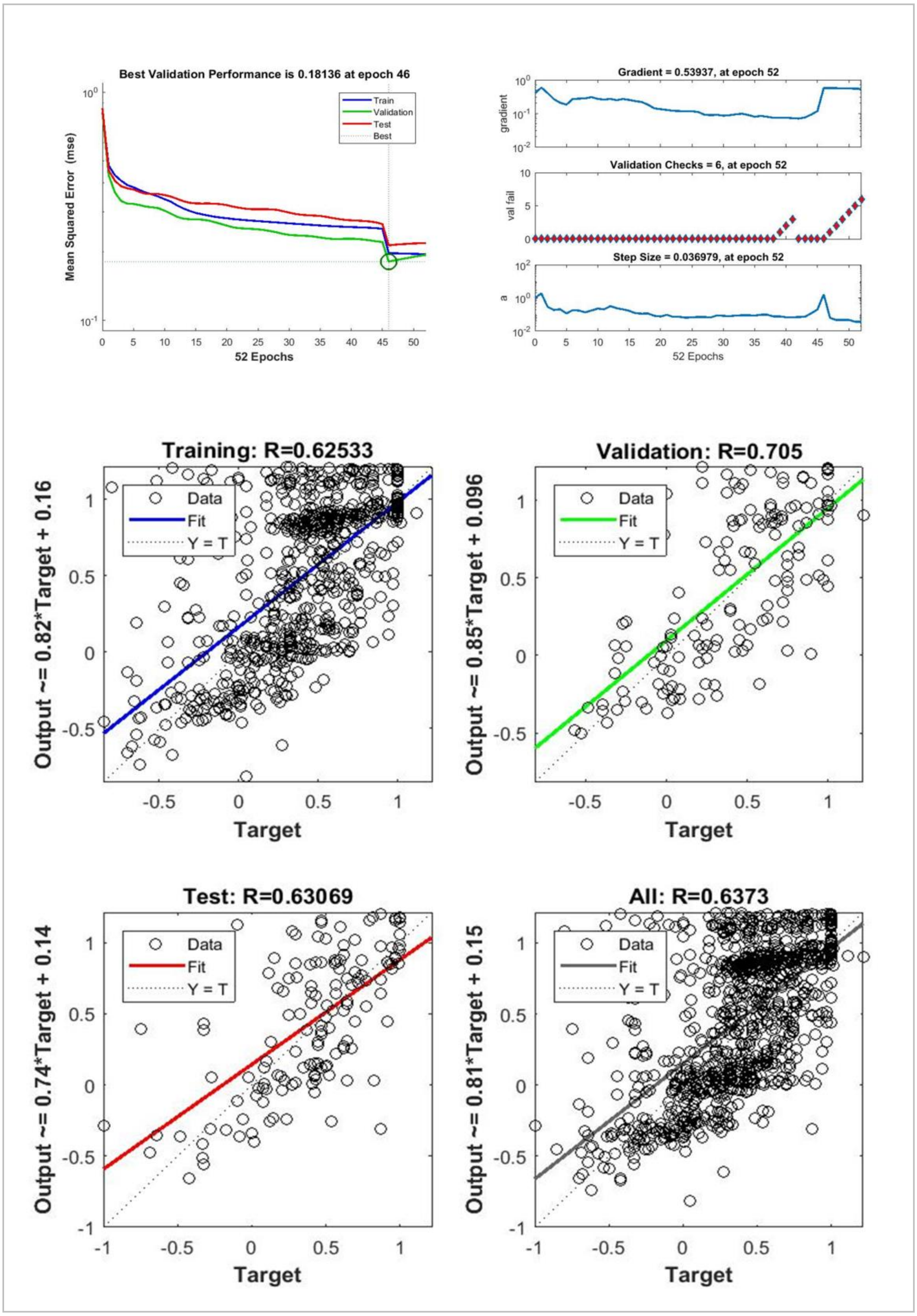
Train GDA model



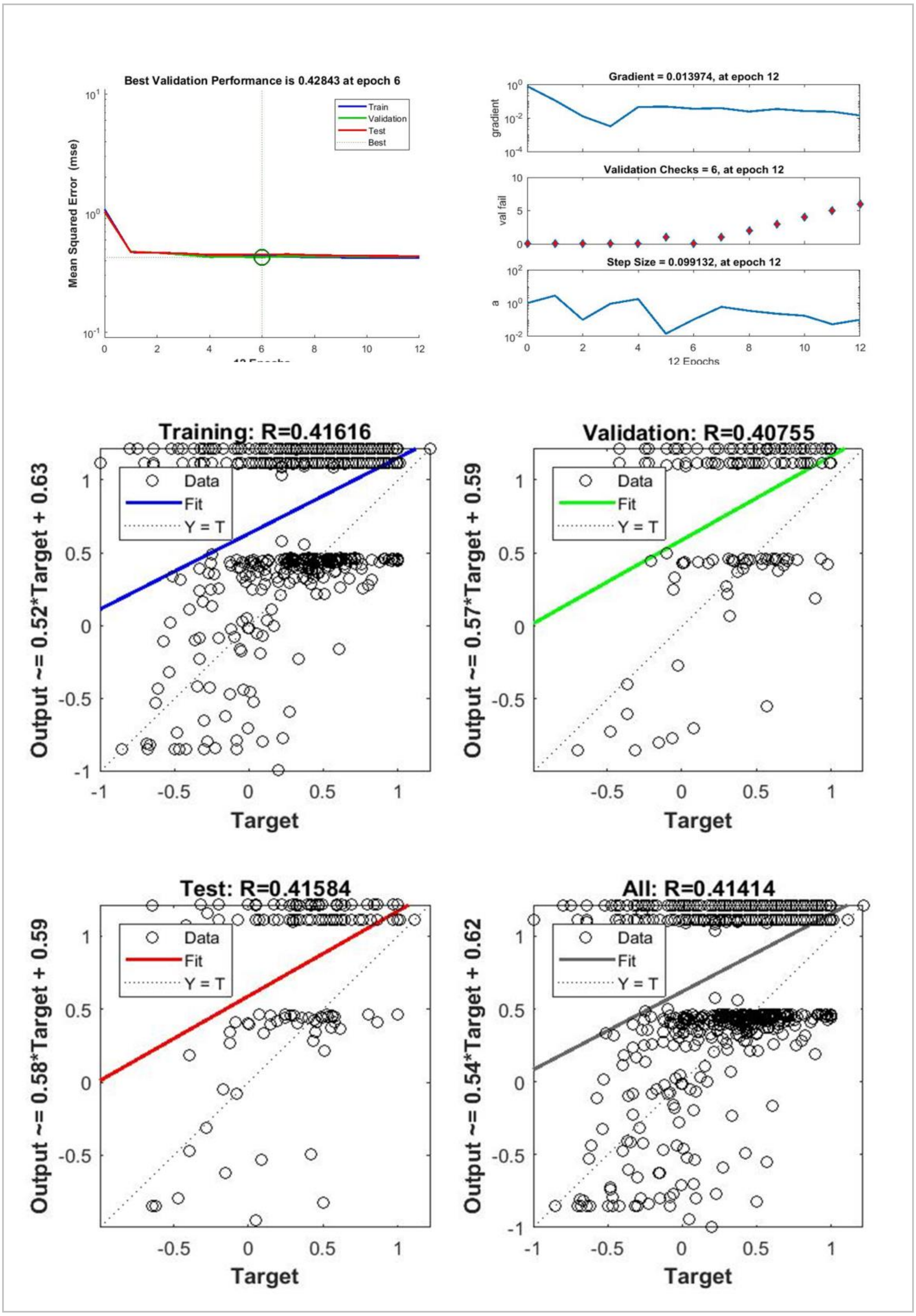
Train SCG model



Train CGP model



Train CG model



Train BF model